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COMBUSTION CHARACTERISTICS OF ALBERTA COALS
WITH SPECIAL REFERENCE TO THEIR SUITABILITY
FOR USE IN AUTOMATIC DOMESTIC STOKERS

- by -

Colin Arthur Genge, B.Sc.

University of Alberta

April 1945.

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COLIN ARTHUR GENCE, B.Sc.

Research Council of Alberta

University of Alberta

A THESIS

Submitted to the University of Alberta
in partial fulfilment of the requirements
for the degree of Master of Science.

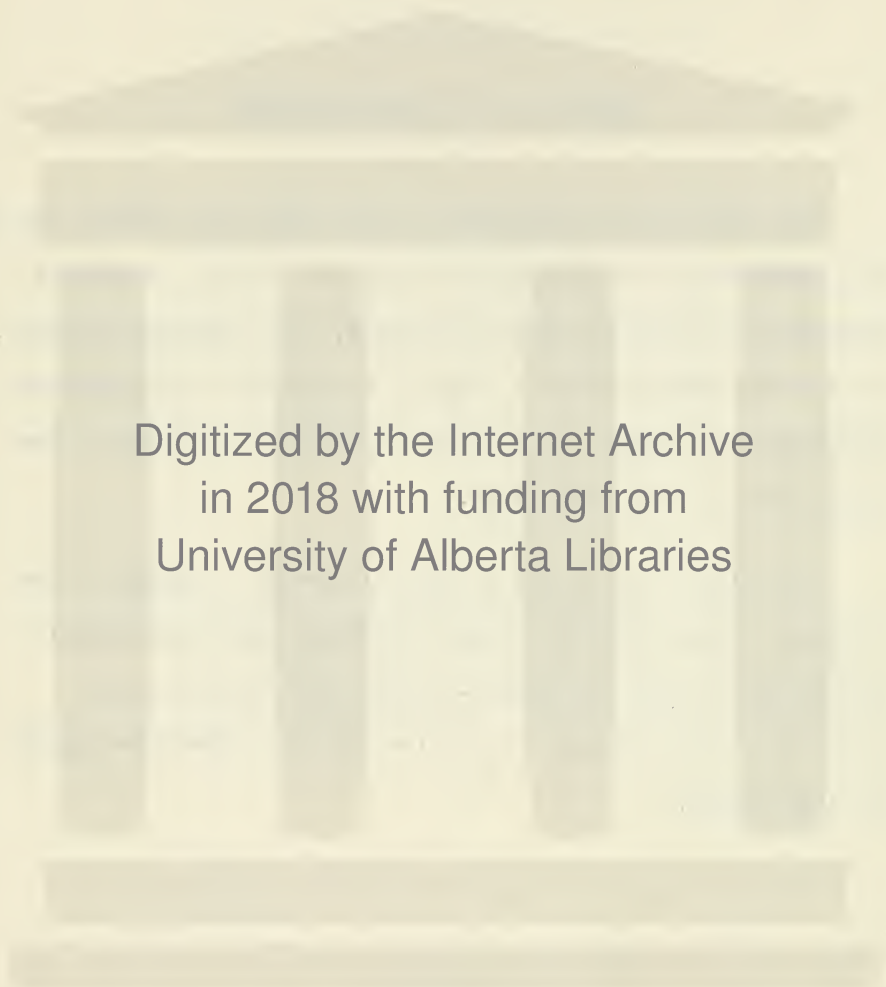
Edmonton, Alberta

April 1945.

PREFACE AND ACKNOWLEDGEMENTS

The investigation described in this thesis was carried out in the laboratories of the Research Council of Alberta, under the direction of Professor Edgar Stansfield, Chief Research Engineer, to whom the writer wishes to express appreciation for advice and assistance throughout the work, and for kindly criticism in the preparation of this manuscript.

The writer also wishes to express thanks to members of the Research Council staff for their assistance, and suggestions; in particular to Miss Catherine A. Fergie for much help in the analytical work involved and to Miss Jacqueline Tate for typing of this thesis.



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COMBUSTION CHARACTERISTICS OF ALBERTA COALS
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INTRODUCTION

Object of Tests. A tendency of the age, the elimination of trouble wherever possible, has led to the increasing use of oil and gas for domestic heating. These fuels only require the turning of a tap instead of the shovelling of coal and ashes. House temperature control by means of thermostats has made the operation of oil and gas furnaces almost automatic.

Coal interests have met this actual and prospective loss of markets by the development of automatic domestic stokers. These stokers use a cheap size of coal and are very easily controlled by thermostats. However shovelling of coal is still necessary, although at less frequent intervals, and ashes must still be removed.

Purchasers of stokers in eastern and central Canada are often told that only United States coals are suitable. Hence the installation of stokers there has done little for Alberta's coal sales.

This investigation therefore was undertaken to find Alberta coals suitable for use in the existing type of stokers. The investigation was not intended to test the efficiency of the stoker nor to devise possible improvements in stoker design. A study of the literature shows that the aim in the majority of stoker investigations

has been the study of the stoker rather than of the suitability of coals for stoker use.

Construction and Operation of Stokers. There are two main types of stokers used on this continent, both of which have been developed mainly in the United States. The underfeed stoker was originally used principally with low volatile (non-coking) bituminous coals. It has since been modified to make it adaptable to many kinds of coal and is widely used right across the continent. The overfeed stoker was developed in the West to burn the free-burning western coals.

In all stokers the coal is fed from a hopper into a retort in the furnace by means of a motor-driven auger. The same motor also supplies air for combustion by means of a fan. The motor is thermostatically controlled and thus the coal feed, and active combustion, only proceed when the house requires heat, although slow combustion by natural draft does proceed with the coal left in the furnace at the end of a firing period. Stokers are also equipped with an adjustable automatic hold-heat control which operates the stoker for a few minutes each hour in order to keep the coal alight in mild weather when the house temperature remains above the thermostat setting for long periods of time.

The motor drives the coal feed auger through belt-driven pulleys and reducing gears. By changing the size of the pulleys the rate of coal feed can be suited to the heat needs of the house and to the calorific value of the coal. The air blast fan is connected directly to the motor shaft. Dampers are used to control the air blast to the retort area in the furnace to suit the coal feed. Some stokers, particularly the underfeed type in which the combustion bed varies in thickness,

are equipped with an air flow damper which automatically opens wider as the combustion bed becomes thicker.

With any stoker incombustible matter in the refuse must be removed either intermittently or continually from the retort. The regular procedure with the underfeed stoker is to remove the ash as clinker through the fire door by means of tongs, this being done from time to time as required. No other method of removal is commonly provided in the domestic sized models. In the overfeed stoker the refuse is pushed off the end of the retort by the advancing coal and is collected in an ash pit below the furnace.

Characteristics of Stoker Coals. Desirable properties common to coals suited to either type of stoker are: freedom from dust, fly-ash, and smoke, proper coal-sizing, and the ability to stay alight in mild weather. There are specific differences however. In the underfeed the coal ash must form a clinker which is strong enough to permit removal, but porous enough to allow the passage of air for combustion to the unburned coal above the clinker ring. This requires that the fusibility of the coal ash must be within narrow limits. The ash percentage must also be moderately low since a high ash coal necessitates too frequent removal of clinker with consequent disturbance of combustion.

The underfeed stoker can burn satisfactorily coals of a wide range in rank, if the ash content is moderately low and if the ash clinkers suitably. However a satisfactory performance is not obtained with a strongly coking coal.

In the overfeed stoker the specifications for coal are notably less stringent than for the underfeed, but the coal must be free-burning;

otherwise a large proportion of unburned coal will drop into the ash pit. Although a low ash coal is desirable, a high ash coal can be burned in an overfeed stoker but requires more attention and more frequent emptying of the ash pit. For an overfeed stoker, the ash may be clinkering or non-clinkering, but trouble may result if the ash clinkers too readily. With such a coal an agglomeration of fused and unfused refuse may bridge the gap between the retort and the opposite wall of the furnace. This 'clinker-bridge' blocks off the air supply and much of the coal fed on to the retort may drop into the ash pit unburned.

Development of Test Procedure. Before a coal was tested in either stoker a preliminary run was made to select a suitable coal feed and air setting. The test runs, which were then begun, were designed to study how the coal would behave in the stoker under the following three conditions:

(a) Cold weather conditions. Will the coal burn at the necessary rate of operation without giving clinker trouble, excessive fly-ash or disturbed fuel bed conditions?

(b) Medium winter weather conditions. Does the coal burn well without trouble of any kind?

(c) Very mild weather conditions. Will the coal stay alight and burn up quickly again when the stoker only operates in response to the hold-heat control for a few minutes each hour?

It was very difficult to ascertain typical conditions in houses, but test periodicities of stoker operation were decided upon as follows:

- (a) Cold weather - 15 minutes on and 15 minutes off.
- (b) Medium winter weather - 10 minutes on and 30 minutes off.
- (c) Very mild weather - 2 minutes on and 58 minutes off.

Published work on stoker tests indicates that the usual method of operation in testing stokers is to use continuous operation. In the few cases where intermittent operation was used, a certain rate was apparently selected with no particular typical household periodicity in mind.

For this investigation a recording device was put on two residential stokers: on an overfeed stoker during the winter of 1943-44 and on an underfeed stoker in the winter of 1944-45. The results from this periodicity recorder indicate that the original choice of the three periodicities listed above is reasonable.

Special Features. These included investigations of:

(1) Clinkering characteristics of the ash, involving chemical analyses, fusion tests, physical studies of clinkers, blending of coals and the chemical treatment of coals, and coal washing.

(2) Fly-ash and dust - this included oiling of coals to reduce dust and the design of a flue trap to catch fly-ash.

(3) Smoke- an apparatus has been built which measures quantitatively the amount of smoke given off by a coal during its combustion.

CONSTRUCTION OF BUILDING

No accommodation could be found on the university campus to house the equipment for this investigation. A small temporary building, of a size suitable for a garage so that it could be sold later as such, therefore was erected just north of the main laboratories of the Research Council.

The floor plan of this building is shown in Figure I. It was erected by a contractor and has shiplap and cedar drop-siding walls, a double pitch shingle roof, and no floor. Two garage-sized windows were put in the south side of the building and a three foot door in the east side. Two coal bins, each built to hold a ton of coal, were built inside the building against the south wall and were fitted with lids and coal openings. Another bin was later placed outside but was used only occasionally.

In designing the chimney it was deemed necessary to have a separate flue of eight by eight inch tile (inside measurement) for each of the two furnaces. It was also thought advisable to separate these two flues by a four inch brick wall. Thus the tiles were enclosed with a four inch wall of bricks and were separated by a four inch thickness of brickwork.

The available formulae for calculating chimney heights for a selected cross sectional area are not applicable to chimneys of less than thirty-five feet. A brick chimney this height could not have been built except at great cost. An approximate calculation using the formula on page 84 of Speers, H.M., Technical Data on Fuel (3rd edition) for the estimated draft needs of the furnaces, gave twenty-five feet as the

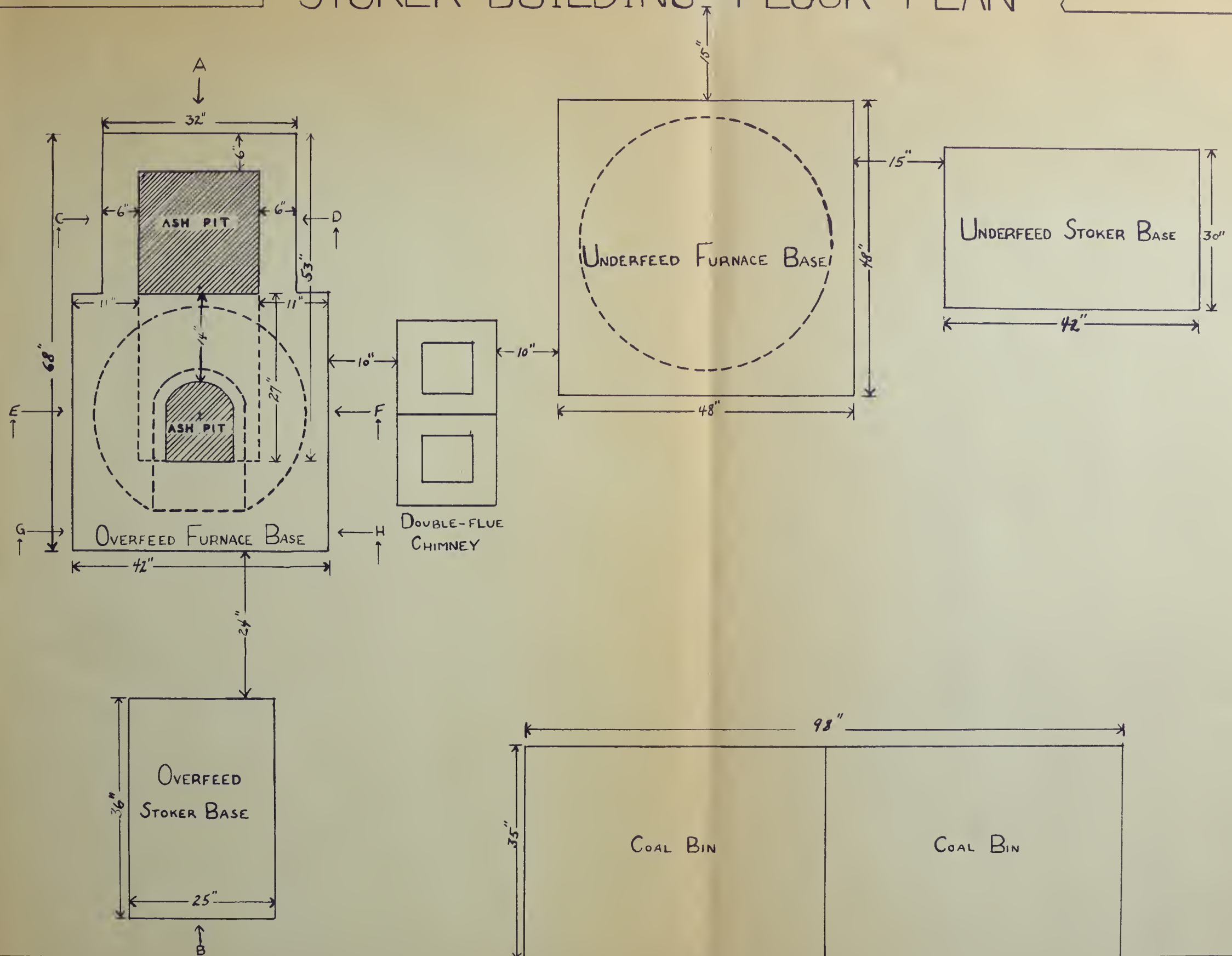
least possible height for the chimney. The bricklayer advised that twenty-five was the maximum height that the building could support. Accordingly a twenty-five foot double flue chimney was erected, although it was expected that it would have to have a temporary extension if stoker tests were to be carried on in warm weather. Such proved the case, and an eight foot length of galvanized sheet iron pipe was added to each flue of the chimney, these being fastened to the projections of tile left for the purpose.

In making the approximate calculation noted above recognition was given to the fact that a stoker-fired furnace with forced draft through the fire requires less chimney draft than does a hand-fired furnace. That is, in a hand-fired furnace the chimney draft must pull the air for combustion through the fire-bed and then must remove the excess air and flue gases from the combustion space in the furnace. In a stoker-fired furnace, however, the chimney draft needs only to remove the excess air and flue gases from the space above the fire bed.

A double roof jack was fastened to the roof conveniently above each furnace inside the building. The inside pipe allowed the heated air to escape, whilst replacement air entered into the building through the annular space.

FIGURE I

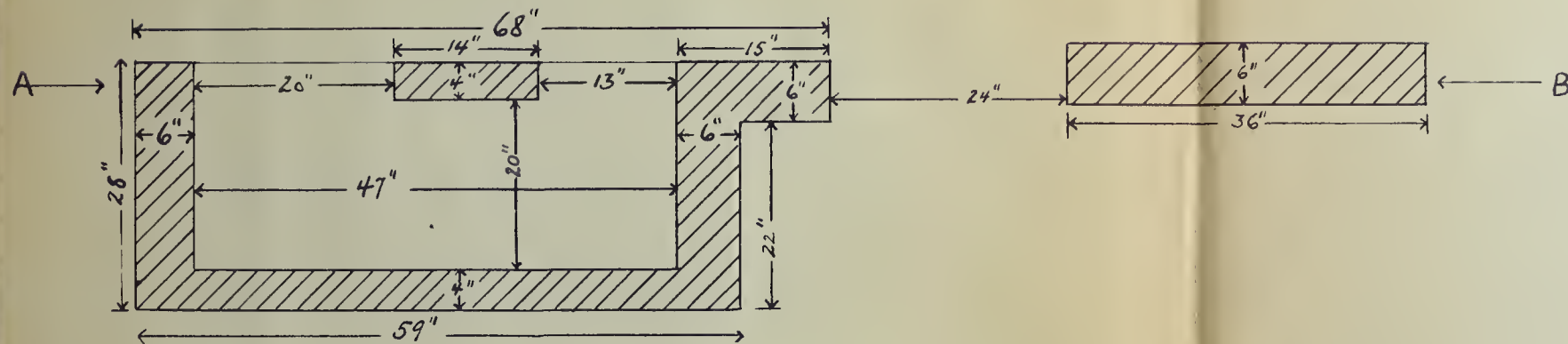
STOKER BUILDING-FLOOR PLAN



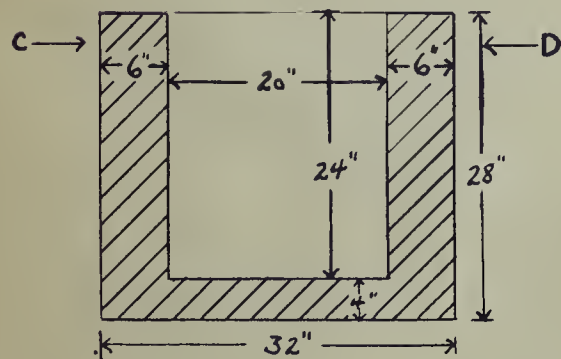
SCALE $\frac{3}{4}" = 1'$

FIGURE II

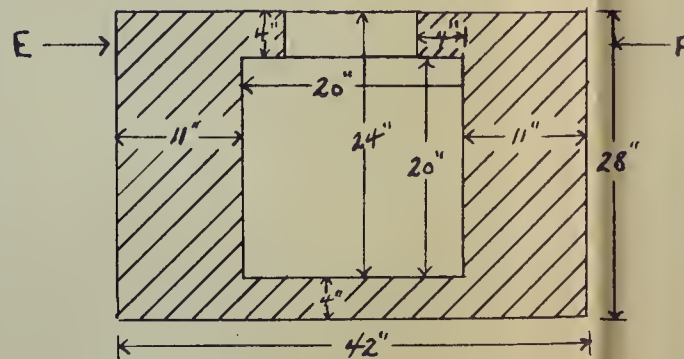
OVERFEED BASES



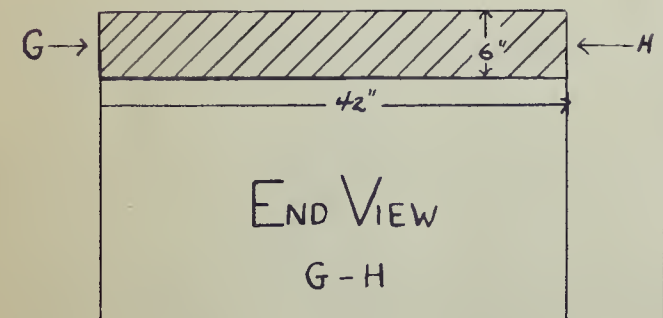
SIDE VIEW
A-B



END VIEW
C-D



END VIEW
E-F



END VIEW
G-H

SCALE $\frac{3}{4}" = 1'$

EQUIPMENT AND INSTALLATION

A. Furnaces.

Two warm air coal furnaces of the usual hand fired type were installed. One was a new cast iron Empire Hy-power No. 18D furnace and the other was a second hand Torrid Zone 210B steel furnace. To adapt these furnaces for stoker use the grates were removed and other adjustments made. Each furnace was approved as satisfactory for the stoker to be installed by the representative for that stoker.

The steel furnace was set on a cement base as shown in Figure I (labelled Underfeed Furnace Base); the furnace is twenty-three inches in diameter at the grate level and thirty-seven inches from grate level to crown. The sectional elevation of this furnace is shown in Figure III. A rectangular radiator, slightly curved to fit the curvature of the back of the furnace, is fitted inside with a baffle plate extending the whole width of the radiator and almost all of its length except for about nine inches at the bottom. This baffle plate forces the flue gases to travel twice the length of the radiator when the direct flue opening is closed, as it is in normal operation of the furnace. The steel furnace has an estimated radiation surface of approximately thirty-four square feet, which is rated as corresponding roughly to 25,000 cubic feet of house space.

The cast iron furnace was set on another cement base shown in Figure I (labelled Overfeed Furnace Base). Further details of this base are given in Figure II. The sectional elevation of the furnace is shown in Figure IV. The furnace has an inside diameter of fifteen inches at the grate level and an inside height of thirty-two inches

grate
from/level to crown. The radiator of heavy cast iron is a circular ring in plan, shaped to fit around the dome-like crown of the furnace. In cross section the radiator is triangular in shape. In normal operation, i.e., with the direct flue damper closed, the flue gases can pass to the chimney only by travelling through this radiator. This cast furnace has an estimated radiation surface of twenty-five square feet which corresponds roughly to a rating of 14,000 cubic feet of house space.

Figure IV shows the installation of this furnace as it was first installed in the stoker building. Later, however, the top part of the furnace was turned clockwise through 120° so that an observer could look through the fire door and see the fire on the overfeed retort.

Each furnace jacket, of galvanized sheet iron, has two outlets on its conical crown, the outlet at the crown of the casing being connected by a 13" pipe with the outside atmosphere through the roof jack and the other outlet opening into the room for use in cold weather. These outlets are equipped with dampers so that the temperature in the building can be controlled within reasonable limits.

Each furnace casing has an opening near its base connected to a large fan, in order to absorb furnace heat by blowing air through the furnace jacket and out through the crown of the casing. In this equipment this forced draft replaces the usual natural circulation of air through the furnace jacket and into the house. These fans are used only when a large amount of heat is being released during the fast rates of operation.

These fans circulate approximately 2100 cubic feet of air a minute. Consequently replacement of this amount of air in the building is necessary. Replacement air enters the building through the annular space of the double roof jack.

B. Fairbanks Morse Stoker - Underfeed.

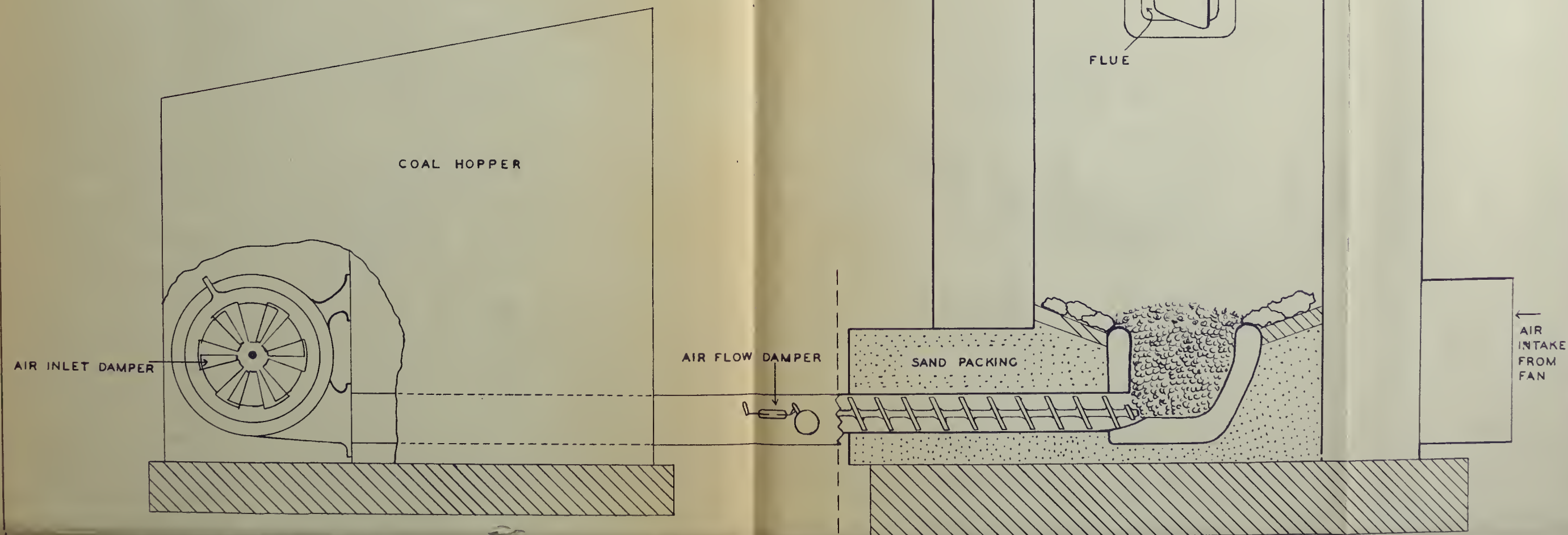
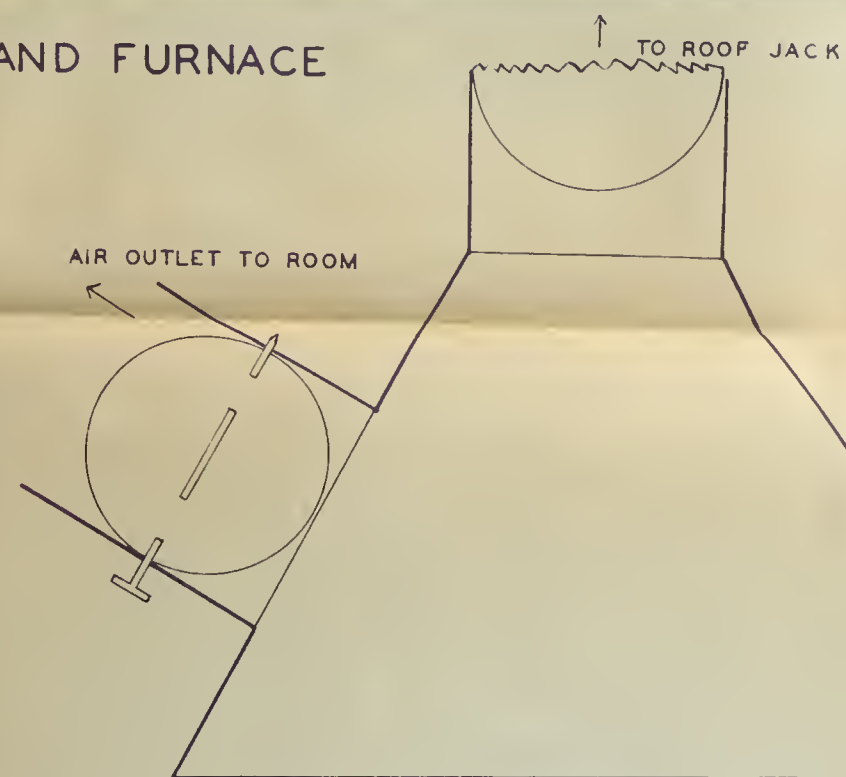
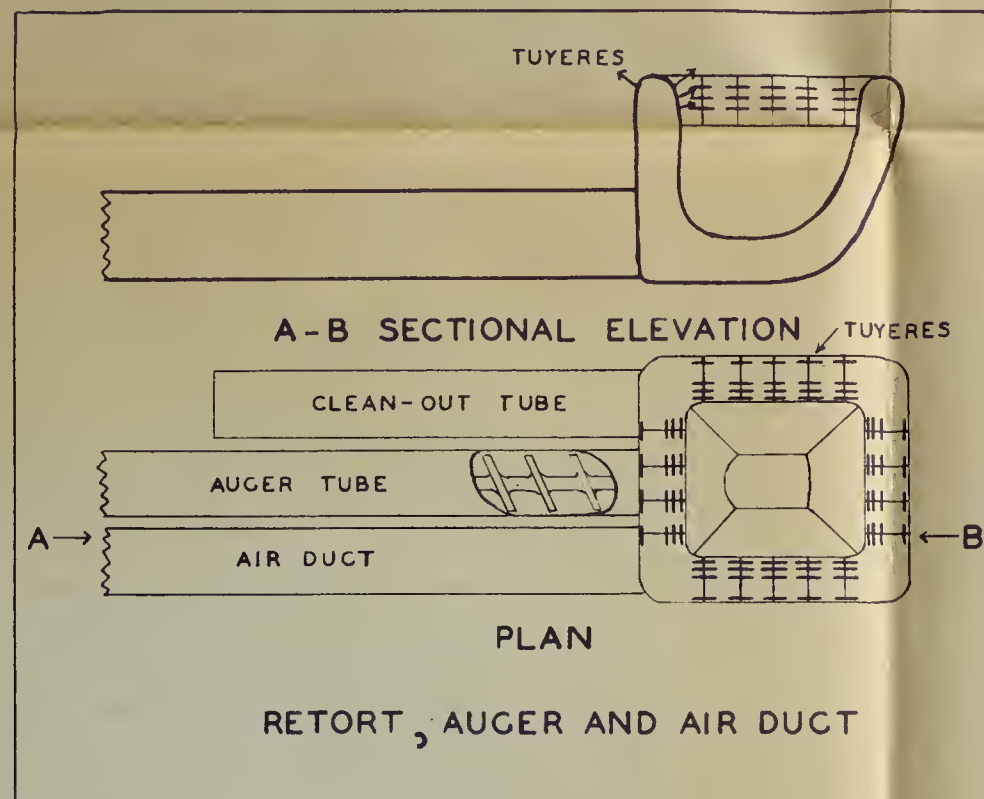
The underfeed stoker used in this investigation was a Fairbanks-Morse Victory model and was rated at 25 pounds of coal an hour with a hopper capacity of approximately 400 pounds. A diagrammatic drawing of this stoker is shown in Figure III.

Under the coal hopper is housed a quarter horse power motor, reducing gears, blower fan and part of the auger. The blower fan is connected directly to the motor shaft while the auger is connected to the motor shaft through reducing gears and a set of pulleys.

The retort is cast iron, rectangular in shape, and has overall dimensions of 10 3/4" (width), 12 1/4" (length) and 9 1/2" (height). In section the retort, as shown in Figure III, is constructed of double walls and bottom with an average air space about 1 1/2" between these walls. The top of this air space is covered by replaceable cast iron sections in which the tuyeres, each 1 3/4" long and 3/16" wide, are located. There are three rows of tuyeres on the inside edge of the retort and one row on the outside edge. The air blast from the blower fan through the air duct to the retort tuyeres is controlled by two dampers: firstly, the air inlet damper which regulates the amount of air allowed to the blower fan, and secondly, the air flow damper which automatically allows more or less air to reach the combustion bed, thus compensating for varying resistance in the fire bed.

FIGURE III

UNDERFEED STOKER AND FURNACE



ELEVATION (MAINLY SECTIONAL)

SCALE 0 8 INCHES 16 24

The opening of the air inlet damper was divided into twelve equal divisions so that a record of the setting for this damper could be recorded for each run. The air flow damper is regulated by means of a turnbuckle. Sixteen full turns of this turnbuckle gives the maximum opening in the air duct; hence the air setting on this damper also could be recorded for each run.

The record of these air settings gives a poor measure of the quantity of air supplied to the retort for any coal. However these records were useful whenever repeat runs were made.

The coal is fed by the auger from the hopper to the retort through the auger tube. The rate of coal feed can be suited to the coal by varying the size of pulleys which connect the motor shaft to the reducing gears. The rate of coal feed in the runs made varied from 13.6 to 28.6 lbs. per hour (continuous operation). The auger feeds by volume; therefore the weight per hour of any setting varies with the size of the coal and its density. The auger is approximately 3 1/2" in diameter and fits snugly in the auger tube. This latter point renders close sizing of coal advisable for this stoker.

When the coal reaches the end of the auger tube, it is pushed up inside the retort and is subjected to a gradual preheat before it reaches the combustion zone. This preheat is furthered by the air blast through the coal from the inside rows of tuyeres. The preheated coal then reaches the active combustion zone, where it burns. The refuse left after combustion is pushed aside by the fresh coal arriving in the combustion bed. This refuse, in the form of loose ash and clinker piles up on the hearth surrounding the retort.

As noted before the refuse is commonly removed from an underfeed stoker as clinker, this being done by lifting the clinkers out through the fire door by means of tongs. Clinkers only are removed, the loose ash being left on the hearth or raked into the fire to be included in clinkers formed later.

The gradual preheat to which the fresh coal is subjected before it reaches the active combustion zone distills off the moisture and much of the volatile matter; the latter must pass through the fire bed where it is mixed with air supplied by the air blast and is usually almost completely burned. Thus the underfeed stoker is designed to burn the volatile part of the coal substance with greater efficiency and less smoke than in ordinary hand firing. This point will be dealt with in greater detail under the description of work done on the smoke properties of Alberta coals.

The tuyeres and air space between the walls of the retort may become blocked up with dust and small pieces of clinker after prolonged use. A clean-out tube, attached to the retort, permits this obstruction to be blown out to allow again the uniform distribution of air to all parts of the combustion bed.

This underfeed stoker is equipped with two safety devices which come into use when a foreign body in the coal, such as a bolt or spike, jams the auger in the auger tube. A shear-pin in the reducing gear system breaks, thus stopping the rotation of the auger before undue strain can be put on the motor. The other device is a trap at the junction between the hopper and the auger tube in which the foreign body is caught and from which the body can be removed. In the one case

when this happened during this investigation, no trouble was encountered in removing the bolt, renewing the shear-pin and continuing the operation of the stoker, although it has been reported that small spikes and bits of mine prop timber may work their way past the trap and lodge between the auger and the auger tube wall, necessitating partial dismantling of the stoker to remove the obstruction.

This Victory (war-time) model was not equipped with the tightly fitting hopper lid previously supplied. Smoke sometimes, when the hopper was empty, backed up the auger tube and issued from the hopper causing inconvenience. In regular practice this would seldom happen.

The underfeed retort was installed in the steel furnace and was packed in with sand, the latter serving as a heat insulator. As indicated in Figure III, rectangular holes 10 1/2" high and 12" wide were cut in the outer casing of the furnace and in the side of the steel furnace proper. Into this opening a galvanized iron box 10 1/2" high, 12" wide and 14" long was tightly fitted. This constituted a passage through which the retort and its connections could be inserted into the furnace. One end of this box was attached to the furnace walls and the other end, fitted with a tongue and grooved cover, projected about six inches out of the furnace casing. The retort rested on about one inch of sand on the furnace base; sand was packed around the retort and into the box around the air duct, auger tube, and clean-out tube. On top of this sand packing a hearth, 2" thick of fire clay and cement, was laid. This hearth at the periphery of the retort was at the level of the lower edge of the outside ring of tuyeres and sloped up from the retort to the furnace walls at an angle of about 15° from the horizontal.

The hopper with the motor, fan, gearing, etc. was set on a cement base which was built to the proper height so that the whole length of the stoker was level. All joints in the auger tube, air duct and clean-out tube were sealed with furnace cement.

The height from the tuyere ring of the retort to the lower edge of the opening into the flue pipe is 24" and from the tuyere ring to the crown of the furnace is 39". The effective grate area at the tuyeres is approximately one half of a square foot.

C. Alberta Coal Stoker - Overfeed

The overfeed stoker used in this investigation was an 'Alberta Coal Stoker' made by Coutt's Machinery, Edmonton. It was rated at a maximum of thirty pounds of lignite per hour and its hopper capacity was about three hundred pounds. This stoker was lent by the manufacturer to the Research Council for this investigation.

Figure IV shows the essential details of this overfeed stoker. The coal feed and blower fan are driven by a quarter horse power motor, the blower fan being connected directly to the motor shaft. The auger is driven through reducing gears and through a belt and set of pulleys.

The cylindrical metal coal hopper, fitted with a lid, has a cone bottom in the center of which there is a rectangular opening where the coal can fall down into the auger. The auger, larger in diameter than that in the underfeed stoker, fits loosely in the auger tube with about one half inch to spare all around. In consequence this stoker does not require as close a sizing of coal as the underfeed stoker requires. The rate of coal feed in the runs made varied from 18.2 to 27.2 pounds per hour (continuous operation).



The retort is a flat platform covered from one end for about half its length; this covered end is connected to the auger tube. The grate, at the other end, is comprised of forty-five steel bars with spaces between them, giving a grate area of approximately one half a square foot. There is an air chamber below the platform through which air from the air duct passes up through the grate. A short clean-out tube is also connected to this air chamber so that any refuse falling between the grate bars can be blown out when necessary. A bleed-off tube from the air duct to the auger tube between the coal hopper and the retort carries a small by-pass current of air along the coal auger to the retort and prevents a back-draft of smoke to the hopper.

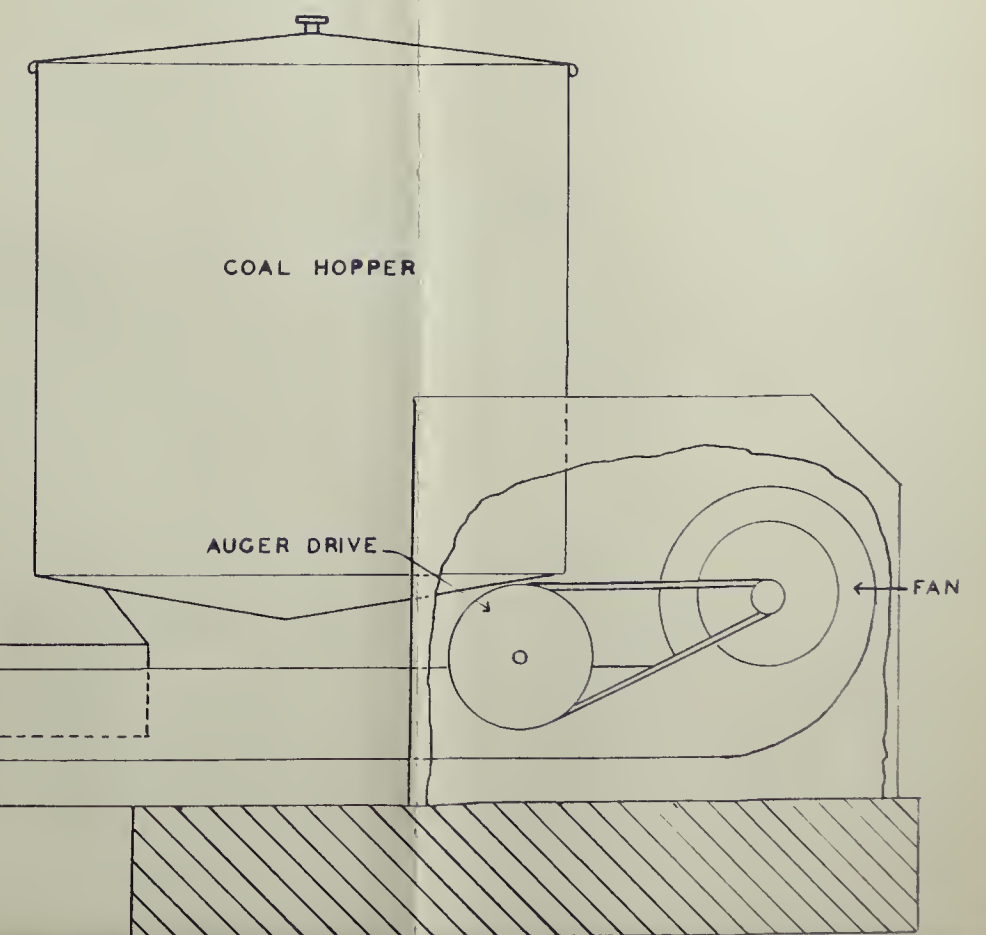
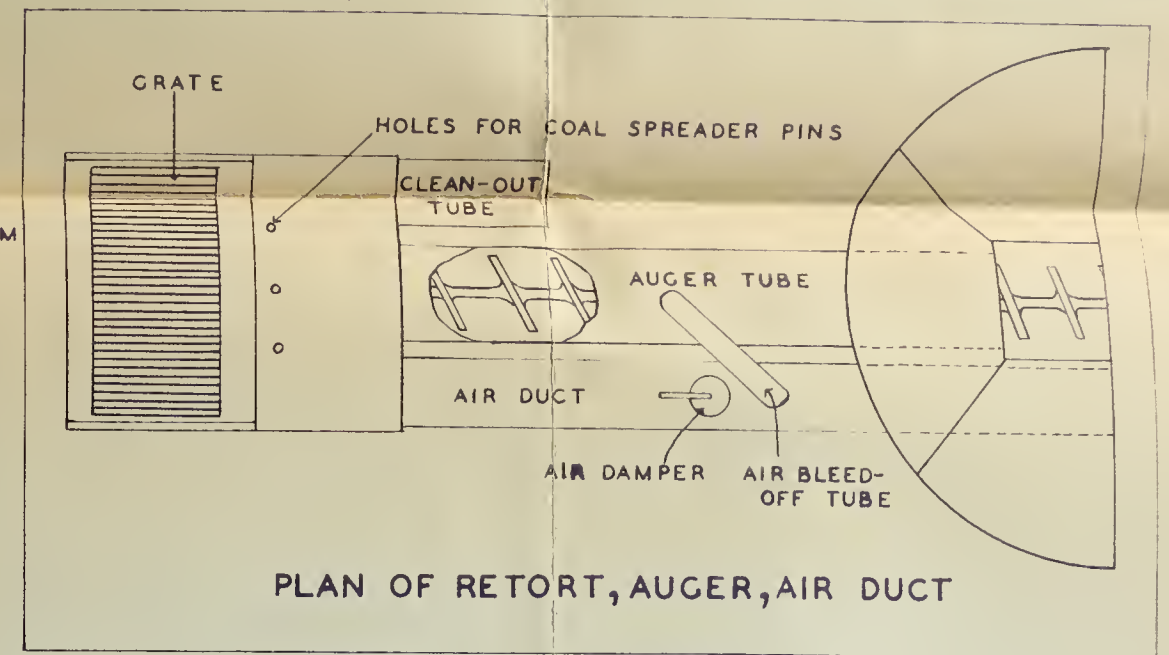
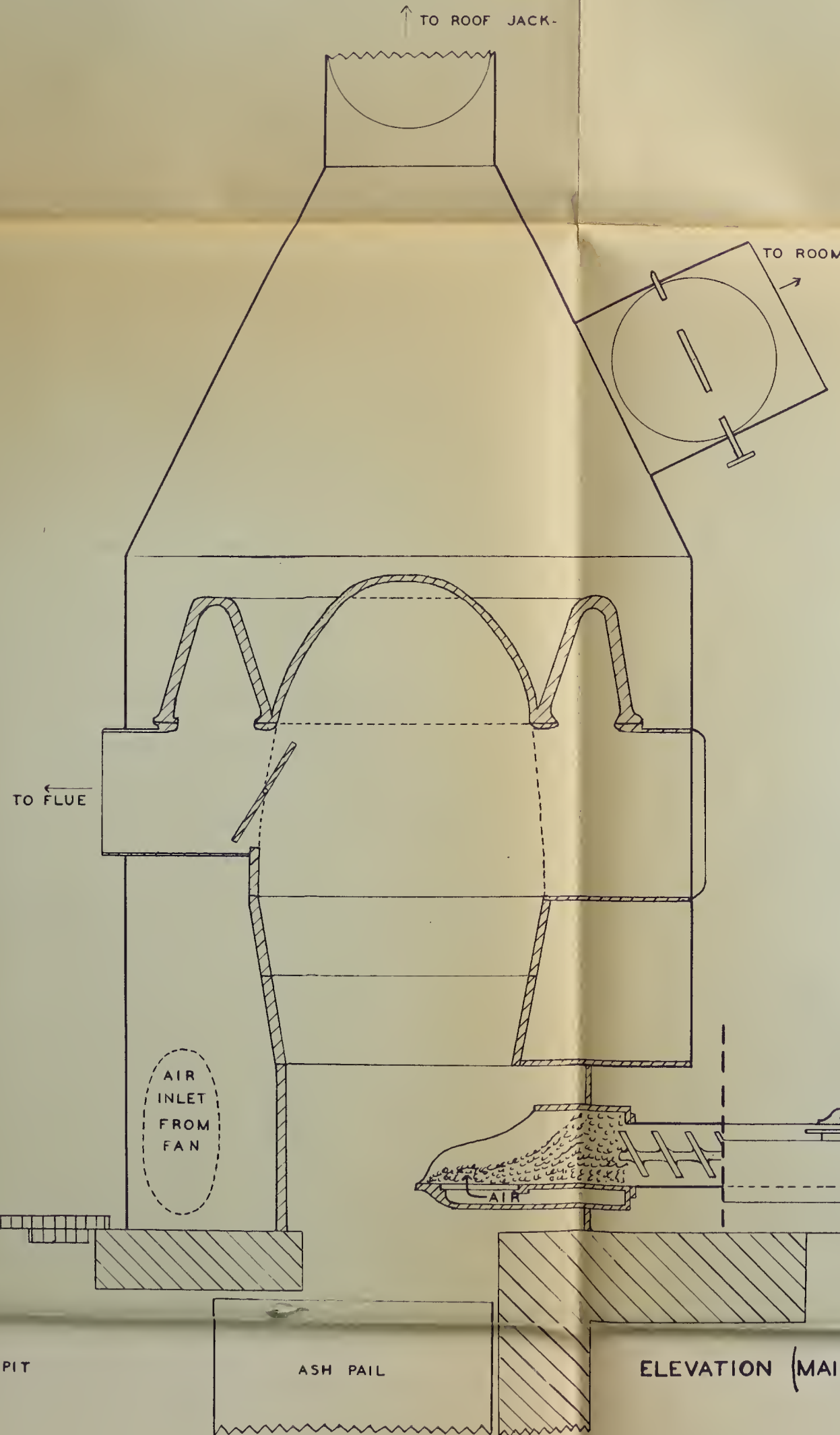
The coal fed on to the retort platform is pushed forward into the active combustion zone over the grate area; combustion is supposedly completed here and the refuse is pushed off the end of the retort into the ash pit. The coal is subjected to a short preheat in the covered part of the retort just before it reaches the grate. The coal flow is distributed over the full width of the grate by means of one or more spreader pins. This preheat will be discussed later in the section on smoke.

The air blast of this overfeed stoker is adjusted by a damper in the air duct. An indicator was put on this damper so that a record could be kept of the air blast used for each run. The ninety degree movement of the damper was divided into twelve equal divisions.

The retort was inserted through the ash door of the cast iron furnace as shown in Figure IV and was held in place with a collar of sheet steel. All openings around the steel collar were sealed with

FIGURE IV

OVERFEED STOKER AND FURNACE



ELEVATION (MAINLY SECTIONAL)

SCALE 0 8 INCHES 16 24

furnace cement. The discharge end of the retort platform is ten inches from the opposite wall of the furnace, and is directly above the pail in the ash pit. The grate is forty inches below the crown of the furnace and twenty-two inches below the bottom of the flue exit.

This stoker is not equipped with any protective device to prevent overloading the motor if any foreign object should lodge between the auger blades and the wall of the auger tube. Such protective devices as have been described for the underfeed stoker apparently are not necessary for the overfeed. The larger auger and the half inch space between the auger blades and tube may allow spikes, bolts, etc. to be pushed through to the retort and into the ash pit. No interruptions in operation of this stoker were experienced during this investigation.

D. Testing Equipment.

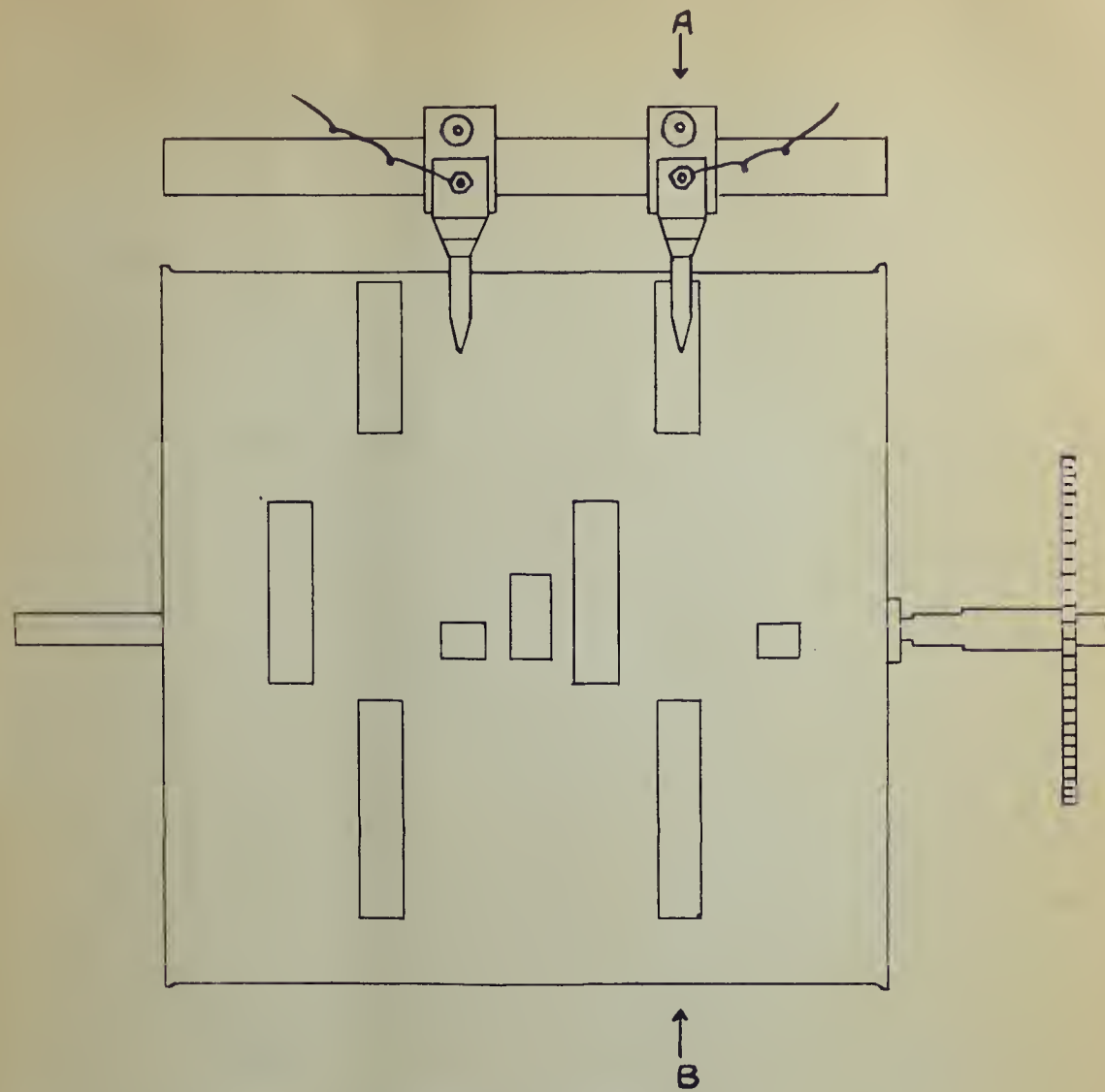
Testing equipment was provided (a) to facilitate correct adjustment of coal and air prior to test runs, (b) to give the desired on and off periods of the test run to be made, (c) to record any irregularities during a test run, (d) to prevent overloading of motors and overheating of furnaces and equipment, (e) to collect fly-ash, (f) to measure combustion bed temperature and (g) to record the distance that a coal burned back into the auger tube during the 58' off periods.

(a) A Ranarex density balance CO₂ recorder was used in the preliminary work on each coal to secure a suitable air setting for the selected coal feed. This recorder was also used in many runs, particularly in the underfeed stoker, as a check record on the regularity of furnace operation.

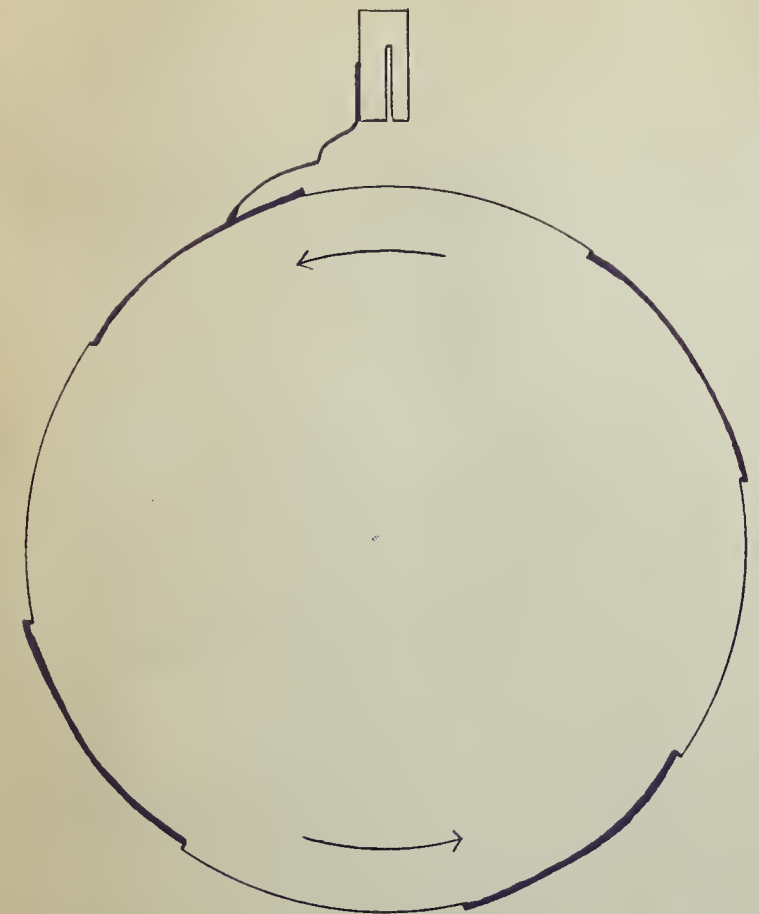
(b) The regular means of controlling the operation of a stoker, i.e., by a house thermostat, was impossible in this investigation.

FIGURE V

TIMER



FRONT ELEVATION



SECTION A-B

SCALE - FULL SIZE

A device for timing the on and off periods of the two stokers used in this investigation was constructed from a large clock. A drum, driven by the clock's mainspring through gears, was covered with a sheet of thin metal over which was placed a layer of celluloid. This drum, etc. is shown in Figure V. The operation of each stoker is controlled by an electric current through a relay switch, connection being made through a metal finger resting on the rotating drum. Slots cut in the celluloid permit periodic electric contact between the finger and the drum, thus closing the relay switch. The drum rotated once in two hours, so it was easy to adapt the length of the slot to the desired time of operation.

Seven paths were made on the drum, with slots to give two each of 15' on 15' off, 10' on 30' off, and 2' on 58' off, and one of 4' on 56' off. The latter path was to be used only if a coal did not give a satisfactory stay-alight fire with a 2' on 58' off periodicity.

The resistance in the relay circuit was high so that sparking as the metal finger contacted the metal on the drum was small. To further minimize this sparking quick makes and breaks were arranged by raising one end of the exposed metal above the surface of the celluloid and by depressing the other end below the celluloid level. Thus the metal finger dropped about a thirty-secondth of an inch as it made contact and again as it broke contact.

Each stoker was equipped with a switch by which the timing device could be by-passed to give continuous stoker operation. This switch was used in the preliminary work prior to a test run being started.

(c) Recording thermometers ($^{\circ}\text{F.}$), were used to record both the flue and warm air temperatures of each furnace. It was not intended that these thermometers be used in calculating efficiencies, but rather

that they should act as a record of the regularity (or irregularity) of furnace operation.

(d) The warm air temperature recording thermometers, having a comparatively low maximum temperature, were protected by means of 'airstats' which were set to stop the operation of the stoker before the range of the recording thermometers was exceeded.

Thermal cut-off switches were included in all motor circuits to prevent overloading of motors.

(e) The variable density of the fly-ash produced by coals under forced draft accounts for the fact that no trap of simple design will retain all the fly-ash produced in the combustion bed. A fly-ash trap for each furnace, illustrated in Figure VI, was designed to give a relative measure of the tendency of coals to produce fly-ash.

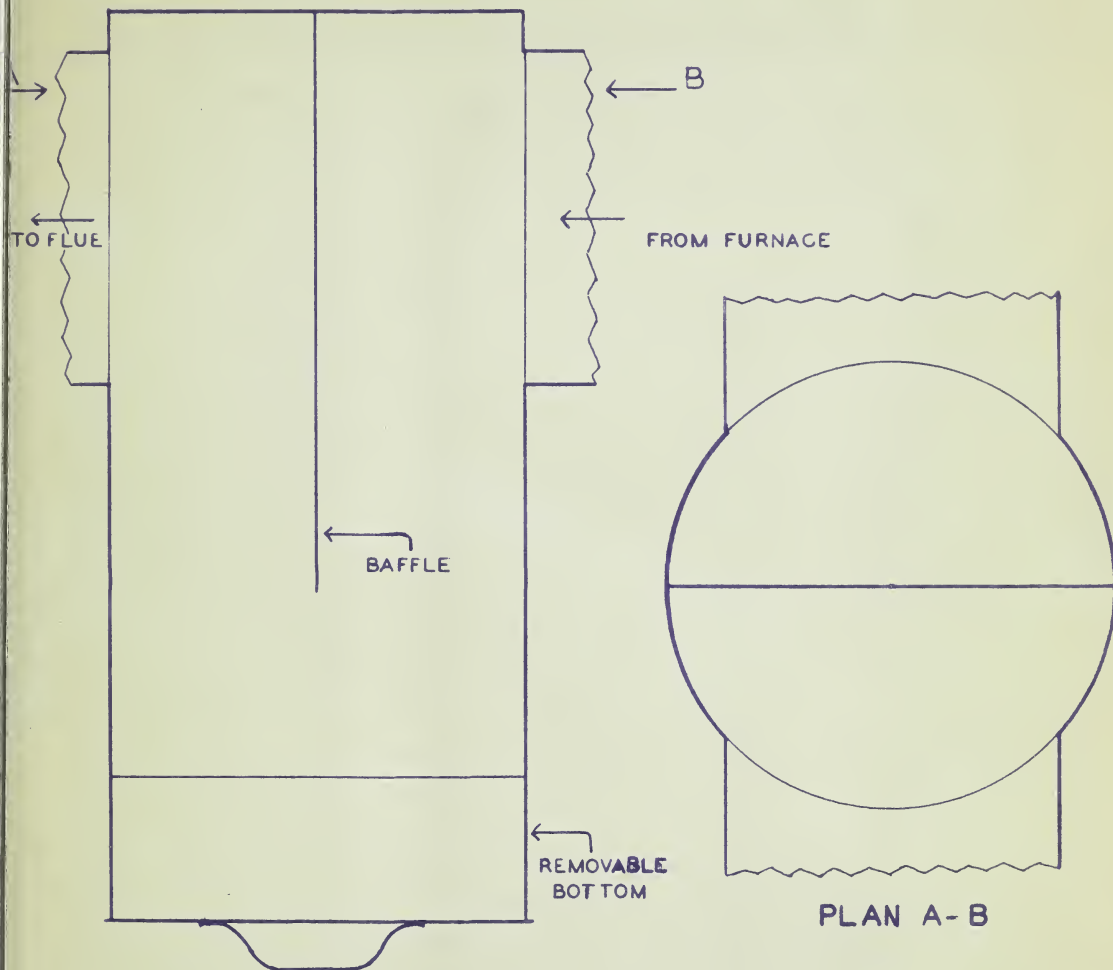
The two main features of this trap are: the baffle placed crosswise to the flow of flue gases and the removable bottom which permitted weighing the fly-ash collected.

These fly-ash traps were not installed until after tests on the first eleven samples were completed. Until this time fly-ash had been measured by weighing the amount deposited in a small silica dish 3" in diameter and 1/2" deep. In the overfeed furnace this dish was placed inside the fire door directly under the flue gas entrance to the radiator. In the underfeed furnace the dish was placed in the clean-out pipe at the bottom of the radiator.

(f) A chromel-alumel thermocouple in a protective case was first used to measure the combustion bed temperatures. The life of a thermocouple was very short and hence an optical pyrometer was used in most tests.

FIGURE VI

FLY ASH TRAP



SECTIONAL ELEVATION

PLAN A-B

SCALE



(g) Numerals were painted on a white background on the auger tubes of both stokers at two inch intervals; a temperature sensitive paint was used which changed colour at approximately 160°F. These numerals served as a check on how far back into the auger tube a coal burned during the 58' off periods. This paint was made by mixing an oil paste of two parts of mercuric iodide (HgI_2) with one part of cuprous iodide (Cu_2I_2).

DESIRABLE AND UNDESIRABLE PROPERTIES OF STOKER COALS

Desirable properties in a coal for either an overfeed or underfeed stoker are: freedom from dust and fly-ash, proper coal sizing and the ability to stay alight in mild weather.

Dust created in shovelling coal into the stoker hopper is very obnoxious to the householder. This dust, worse from some coals than from others, can be reduced by screening and oiling. Oiling a coal, besides diminishing the dust, increases the calorific value by 70-100 B.t.u. per pound.

Fly-ash. Burning a coal under forced draft necessarily produces more fly-ash than does ordinary hand firing. This fly-ash, composed of ash and carbon, varies greatly in particle size and density and hence settles out progressively in the furnace, flue, chimney, and outside the building. Fly-ash, besides representing the loss of a small amount of combustible material, insulates radiation space occasioning loss in efficiency of heat transfer. While all coals produce fly-ash, a coal to be well suited to stoker use, should not produce an excessive amount since, even with a normal amount of fly-ash, this must be removed from the furnace and flues at the end of each heating season. Ordinarily a high ash coal produces more fly-ash than does a low ash coal.

Sizing. Correct sizing of coal is very important in keeping fly-ash to a minimum. The larger pieces of coal should go through the auger without excessive fracturing. However, excessive fines, whether originally in the coal or produced by fracture in the auger, will cause fly-ash trouble. The size of coal suited to stoker use depends on the dimensions

of the auger and auger tube of the individual stoker, but sizing between $1/4"$ and $1\ 3/4"$ limits is usually satisfactory, although closer screening, e.g., between $3/4"$ and $1\ 1/4"$, produces less fly-ash.

Another difficulty sometimes encountered with a poorly sized coal is the bridging of coal in the hopper, which prevents the coal going through the auger tube to the retort, and usually results in the fire going out. The danger of bridging is much increased when the coal is wet. This bridging happened once during this investigation. In this case the coal was poorly sized - from 0 to about $3\ 1/2"$ - and was very wet when received.

Stay-alight. The ability of a coal to stay alight in mild weather when the stoker operates only on the automatic timer is a very important characteristic. This property is related to the ignitability of the coal and depends on its rank. However, considerable leeway is provided by most of the automatic timers superimposed on the thermostat since they are adjustable and can usually be set to give a satisfactory stay-alight fire for any coal.

Other desirable properties which vary notably with the type of stoker are: smoke, combustion characteristics, and ash and clinker formation.

Smoke issuing from a chimney is lost heat value in addition to being a nuisance to the neighbourhood. Smoky fuels also cause the radiation surfaces of the furnace and flue pipes to be covered with an insulating layer of soot, thus occasioning a further and more serious loss of heat.

In the underfeed stoker the volatile matter driven off during the preheat is largely burned during its passage up through the active combustion zone, and consequently the underfeed stoker is adapted to burn

the smoky coals. In the overfeed stoker there is no such provision, but this stoker is only intended to burn free-burning lower rank coals that are smokeless or only slightly smoky.

Combustion Characteristics. The difference in the combustion bed thickness and heat holding ability between the underfeed and overfeed retorts accounts for the fact that (non-coking) high rank coals are suited to the former but not to the latter. High rank coals, which are more difficult to ignite and take longer to burn than low rank coals, would drop from the overfeed retort into the ash pit with a prohibitive loss of combustible material, since the coal is in the active combustion zone for not more than one hour at a periodicity of 15' on 15' off. High rank (non-coking) coals can be burned efficiently in the underfeed stoker, since here the fire bed is much thicker and holds its heat better. In the underfeed nothing is supposedly removed except clinker. There is usually every chance that a piece of coal, which may escape burning for a time, must eventually burn; the loss of combustible in the clinker is ordinarily very small.

Strongly coking coals cannot be efficiently burned in the ordinary underfeed stoker. The coke formed in the lower zone of the fire is far more difficult to burn than the coal and therefore passes up through the combustion zone only partially burned. This coke may build up as much as two and a half feet above the fire. Such a formation is known as a 'coke-tree'. When it collapses much of the unburned coke falls outside of the hot fire zone and does not burn.

Ash and Clinker Formation. For the underfeed stoker a coal with a low percentage of ash, with satisfactory clinkering properties, is required. A high ash coal results in the rapid accumulation of clinker and ash in

the furnace. This disturbs the smooth and efficient operation of the stoker regardless of whether it is allowed to accumulate until the normal cleaning period or is removed at more frequent intervals. A coal with more than one pound of ash per therm (100,000 B.t.u.), i.e., 10% on a 10,000 B.t.u. coal, is inadvisable. This method of rating the ash relative to the calorific value of the coal seems a much fairer criterion than as a straight per cent of ash. For this reason Table V lists the pounds of ash per therm for each coal.

A satisfactory clinker is one which is strong enough to allow removal with tongs, but porous enough to permit the passage of air for combustion to the unburned coal above the clinker ring. The word porous is ambiguous; clinkers in which there are passages through which a fluid can pass easily, and clinkers with enclosed air spaces might both be described as porous, but only the former would permit the free passage of air to the fire-bed. In this report a clinker with visible air passages is defined as porous, while a clinker with enclosed air spaces is defined as cellular. No method was found for determining the porosity of a clinker other than by visual observation. The percentage air space of the clinkers in Table IX are calculated from their determined true and apparent specific gravities.

Ash and clinker specifications for the overfeed stoker are notably less stringent. A low ash coal is desirable but not required. The coal ash, however, must not be too fusible or trouble in the form of a 'clinker-bridge' may result. This is an agglomeration of fused and unfused refuse which bridges across the fire pot and lodges against the opposite wall instead of dropping into the ash pit. This 'clinker-bridge' blocks off the air supply causing most of the fresh coal to drop into

the ash pit before being more than partially burned. Small clinkers are not detrimental to the smooth operation of the overfeed stoker.

In conclusion, coal for:

An underfeed stoker should be closely sized, free from dust, preferably oiled, non-caking, of low ash content with ash forming a coherent and porous clinker.

An overfeed stoker should be closely sized, free from dust, preferably oiled, free burning, smokeless, and the ash should not form a strong, hard clinker.

OBJECTS OF TESTS

The Research Council of Alberta has received enquiries from time to time from stoker owners as to good Alberta coals to purchase for stoker use. It is evident from the foregoing discussion of the desirable properties for a stoker coal that it is difficult to predict from its analysis whether or not a particular coal would burn satisfactorily in either type of stoker. This is especially difficult for the underfeed stoker. A more reliable prediction can only be given after a stoker test has been made on the coal.

Accordingly, the objects of the tests can be stated thus: to find the Alberta coals suited to the overfeed stokers in common use in western Canada, and to find Alberta coals suited to underfeed stokers in common use in both western and eastern Canada. For the latter, two types of coal were considered: lower rank coals for domestic markets and high rank coals for either domestic or distant markets.

SELECTION OF TEST PERIODICITY

As noted in the introduction it was desired to test each coal under three different conditions and three different stoker periodicities were chosen. These rates were: 15' on 15' off, 10' on 30' off and 2' on 58' off. No precedent could be found as to what periodicities should be used and for this reason a recording device was placed on two residential stokers, on an overfeed stoker in the home of Dr. R.F. Shaner during the winter of 1943-44 and on an underfeed stoker in the home of Mr. Colin Campbell in 1944-45. Figure VII is a pictorial representation of the operation of Mr. Campbell's stoker on three typical days.

The results obtained for this stoker periodicity recorder are summarized in Tables I and II. The owner of each stoker made a practice of reducing the temperature setting on his thermostat at night, usually before midnight, and of raising the setting again in the morning, usually after six o'clock but before nine o'clock. Therefore from each twenty-four hour record of stoker periodicity, two periods of six hours each were chosen, one period from 9 A.M. to 3 P.M. and the other from midnight to 6 A.M. The latter period gives a better picture of typical stoker operation than does the 9 A.M. to 3 P.M. period because the heat needs of a house are usually more regular during the night than during the day.

The winter of 1943-44 was mild and for this reason there are fewer results in Table I than in Table II; neither table includes periodicities during mild weather when the automatic hold-fire control largely controls the operation of the stoker.

These tables show that 15' on 15' off and 10' on 30' off periodicities selected for this investigation are reasonable to typify extra cold and cold winter weather. The third periodicity, 2' on 58' off, represented stay-alight conditions.

· FIGURE VII

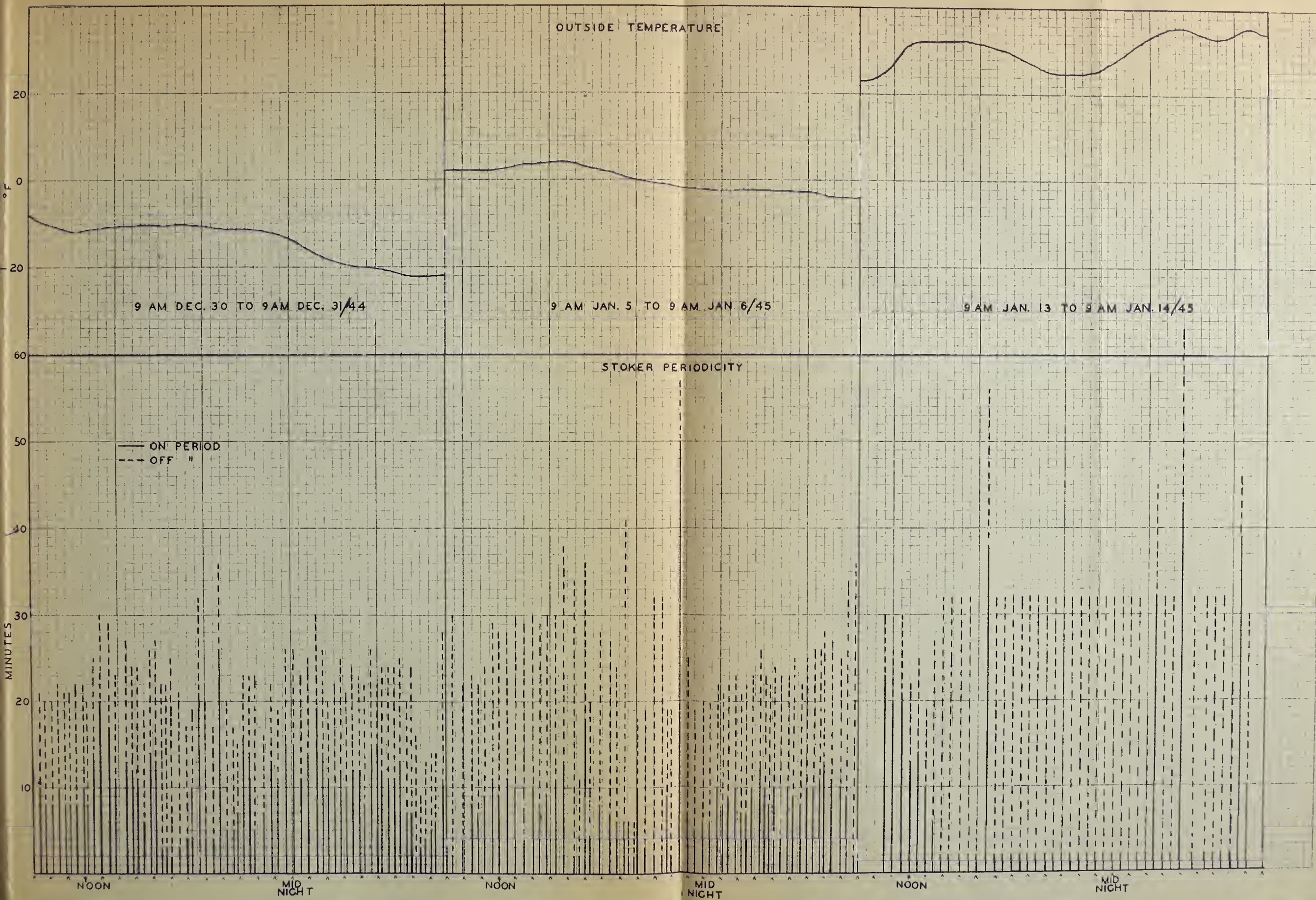


TABLE II

Stoker Periodicity
1944-45 - Underfeed Stoker

Outside Temperature °F	Midnight to 6 A.M.							Outside Temperature °F	9 A.M. to 3 P.M.						
	Max. On Period	Min. On Period	Av. On Period	Max. Off Period	Min. Off Period	Av. Off Period	Time On		Max. On Period	Min. On Period	Av. On Period	Max. Off Period	Min. Off Period	Av. Off Period	Time On
	Min.	Min.	Min.	Min.	Min.	Min.	%		Min.	Min.	Min.	Min.	Min.	Min.	%
-22	78	1	14	39	6	13	52	-21	28	2	13	12	2	8	62
-19	19	8	12	14	10	12	50	-20	23	3	15	15	5	10	60
-18	46	2	19	32	6	10	76	-18	63	2	15	30	5	14	52
-16	66	1	24	26	6	12	67	-17	20	1	13	31	7	11	54
-15	45	2	12	32	5	14	46	-16	35	10	17	8	3	7	71
-15	29	2	11	32	3	12	48	-11	52	2	18	30	5	15	55
-13	43	10	15	8	3	6	71	-11	20	8	11	14	10	12	48
-12	34	1	12	32	5	14	46	-10	53	2	13	31	4	11	54
-11	69	2	16	30	2	15	52	-8	76	2	18	30	7	13	58
-9	31	1	7	46	7	17	29	-6	63	1	8	32	5	20	29
-9	62	2	12	32	3	21	36	-5	13	3	10	22	14	18	36
-9	22	8	13	10	3	9	59	-5	25	4	13	14	6	8	62
-6	14	8	11	22	15	19	27	-4	55	2	7	38	11	18	28
-4	31	2	11	30	1	15	42	-2	20	2	12	20	7	10	55
-4	11	8	9	20	17	19	32	+1	55	1	7	32	14	30	19
-3	66	2	14	31	3	10	58	+1	46	1	13	31	6	11	54
-2	13	7	9	16	12	13	41	+2	45	1	13	31	5	10	57
-1	56	1	10	32	4	17	37	+3	11	2	8	34	15	20	29
-1	35	2	9	30	8	20	31	+3	40	2	13	32	3	13	50

TABLE II (cont'd)

Stoker Periodicity
1944-45 - Underfeed Stoker

Outside Temperature	Midnight to 6 A.M.							Outside Temperature	9 A.M. to 3 P.M.						
	Max. On Period	Min. On Period	Av. On Period	Max. Off Period	Min. Off Period	Av. Off Period	Time On		Max. On Period	Min. On Period	Av. On Period	Max. Off Period	Min. Off Period	Av. Off Period	Time On
	°F Min.	°F Min.	°F Min.	°F Min.	°F Min.	°F Min.	%		°F Min.	°F Min.	°F Min.	°F Min.	°F Min.	°F Min.	%
+2	29	1	7	32	2	22	24	+4	55	1	11	32	7	19	37
+3	12	8	10	12	9	10	50	+5	27	2	9	32	2	14	39
+4	40	2	6	32	6	17	26	+6	49	1	12	32	4	17	41
+4	35	2	9	32	6	23	28	+10	10	2	7	38	11	18	28
+4	145	1	24	32	4	21	53								
+12	102	1	24	32	6	19	51								
+13	44	2	10	30	1	20	33								
+14	39	1	9	32	4	20	31								

TEST PROCEDURE

Samples of coal for stoker tests ranged in amount from half a ton to a ton and a half and were nearly all received in sacks. Upon arrival this coal was sampled as the coal was emptied into a bin; this sample for analysis, of approximately sixty pounds per ton of coal, was taken by removing about a half a pound of coal with a shovel from each of at least three places in each sack. Proximate, ultimate, calorific, and ash analyses, as well as fusion tests, were made for each coal.

Both stokers and both furnaces were thoroughly cleaned of all coal and refuse from previous tests. The tuyeres on the underfeed and the grate area on the overfeed were inspected, and cleaned if choked up with refuse. The coal feed was adjusted to suit the calorific value of the coal by using the proper pulleys. Coal was then put into each hopper and the stoker turned on to feed the coal through to the retort; the stoker was then turned off and a fire kindled on top of the coal. When the coal was well alight the stoker was again switched on and left operating, using the by-pass switch, until a hot fire had built up in the retort area. In the underfeed the air supply was cut to a minimum so that a normal fuel bed approximately eight inches deep built up quickly. Once a good fire had been attained the stoker was then put on the 15' on 15' off periodicity and left running at this rate for several hours for conditions in the furnace to reach equilibrium.

Adjustments were then made on the air blast dampers to suit the amount of coal being fed into the retort. In the underfeed stoker the proper air setting is that which supplies the minimum air necessary to burn the coal efficiently without allowing unburned coal to build up in the

retort area. In general higher rank coals, e.g., semi-anthracite, require more air per minute than do the free burning lower rank coals even though both are fed into the retort at rates to give approximately the same rate of heat release. The CO₂ recorder was used at this time to check on the flue gas content. In general slightly more air than that required to give the maximum percentage of CO₂ in the flue gas was needed to prevent unburned coal building up in the underfeed retort.

In the overfeed stoker a proper air setting will give an optimum balance among three conflicting criteria: minimum combustible material in the refuse, maximum per cent of CO₂ in the flue gas, and minimum of sparking from the fuel bed. In the preliminary work on the overfeed stoker several air settings were tried for short runs of from one to two hours. Visual observation of the fire, the CO₂ record, and the combustible material in the refuse were duly considered in order to select the best air setting.

Having decided on suitable air settings the stokers were then made ready for the test runs. Refuse from the stokers and fly-ash from the flue receptacle were removed. Usually the 15' on 15' off run in the underfeed and the 2' on 58' off run in the overfeed were begun at the same time. Then the 10' on 30' off runs were made in each stoker, and finally the 2' on 58' off and 15' on 15' off runs were made in the underfeed and overfeed respectively. The above schedule applied when a coal was tested in both stokers and it gave a reasonably uniform heat outflow in the stoker building. These runs were of variable length but commonly lasted from twenty-four to forty-eight hours each.

The approximate rate of feed for each stoker being known from the preliminary work, sufficient coal for at least twenty-four hours, and for the whole length of the run, if possible, was weighed into each hopper.

The starting and finishing times for each run were recorded; the times at which clinkers were removed from the underfeed were also recorded. In general it was attempted to make these clinker removals during the two fast rates of operation at such intervals of time as to simulate clinker removals in a household installation, that is, clinkers were removed twice a day for the 15' on 15' off rate and once a day for the 10' on 30' off rate. However, in the case of a high ash coal in the 15' on 15' off rate, clinkers were removed when necessary. In the 2' on 58' off rate clinkers were not removed until the end of the run. Flue temperature and warm air temperature records were kept for all runs, and visual observation of the fire in each furnace was recorded for all runs. A CO₂ record for the 15' on 15' off runs was kept and for these runs the fire bed temperature as determined by the optical pyrometer or thermocouple was also recorded. In the 2' on 58' off runs a check was kept on the temperature sensitive paint numerals.

At the end of the run the coal remaining in the hopper was weighed out. The fly-ash caught in the flue receptacle was weighed and kept for analysis. Refuse in the overfeed ash receptacle was weighed and saved for combustible matter analysis. Clinkers from the underfeed were not weighed, but were analyzed for combustible matter. Clinkers from the underfeed and 'clinker-bridges' from the overfeed were also tested for true and apparent specific gravities.

REPORT OF TESTS

TABLE III

Samples Tested

Sample Number (all of 1944)	Source		Classification	Sizing inches	Tested in
601	Lethbridge	B 9	High Vol. C Bit.	1/8 - 1 1/8	U, O
* 602 ‡	(Power House)	?	" " " "	*** 0 - 1 1/2	U, O
603	Edmonton	E 2	Subbituminous B	***3/4 - 1 1/4	U, O
604	Drumheller	E 10	" "	5/8 - 1 5/16	U, O
605	Saunders	B 4	High Vol. C.Bit.	5/8 - 1 5/8	U, O
** 606	(Kentucky)		" " A "	*** 0 - 1	U
607	Lethbridge	B 9	" " C "	3/8 - 5/8	U, O
608	Tofield	E 3	Subbituminous C	*** 0 - 2	U, O
609 ‡	Drumheller	E 10	" B	*** 0 - 1	U, O
610	Cascade	K 7	Semi-anthracite	1/4 - 1 1/2	U
611	Sheerness	E 9	Subbituminous C	3/8 - 1 1/4	U, O
612	Coalspur	B 3	High Vol. C Bit.	***1/4 - 3/4	U, O
613	Redcliff	B 22	Subbituminous C	*** 0 - 3	O
614	Pembina	E 1	" B	***3/4 - 1 1/4	U, O
615	Brooks	B 14	" B	1 1/4 - 2	O
616	Cascade	K 7	Semi-anthracite	1/4 - 1 1/2	U
617	Mt. Park	K 3	Med. Vol. Bit.	3/8 - 1 5/8	U
618	Camrose	E 4	Subbituminous C	3/4 - 1 1/2	O
619	Taber	B 12	" B	1/4 - 1 3/8	O
620	Carbon	E 8	" B	***3/4 - 1 1/4	O
621	Crowsnest	K 10	Med. Vol. Bit.	3/8 - 1 1/4	U
622 ‡	Edmonton	E 2	Subbituminous C	*** 0 - 3 1/2	O

Notes re Table III

- *602 - obtained from University power plant and thought to be from Coalspur area; its analysis however was not that of Coalspur coal.
- **606 - obtained from a dealer in Winnipeg. It is supposedly widely sold as an underfeed stoker coal and it was desired to compare its combustion properties with Alberta coals. This was not the coal normally sold but was a war-time substitute.
- *** - approximate only since sizing not supplied by mine operator.
- † - these samples were taken from consignments received at the University power plant.

A. Detailed Report of one Run in Each Stoker.

To exemplify the methods adopted and the observations taken during a test run on a stoker coal, a log for one run in each stoker is given below.

General Data for Both Stoker Tests

Sample number	605/44 (Saunders Area)
Classification	High Volatile C Bituminous
Date	March 28, 29, 30, 1944.
Ash (as fired)	8.8%
Calorific value (gross, as fired)	11,430 B.t.u./pound
Ash per therm	0.77 pounds
Fuel ratio (as fired)	1.60

General remarks - coal very dusty; suggest advisability of oiling; sizing well suited to both stokers - 1 5/8" - 5/8".

Summary of Observations

(a) In Underfeed Stoker.

Periodicity	15' on 15' off
Run number	56
Length of run	47 hrs. 21 min.
Weight of coal burned	427 lbs.
Rate of feed - medium	- 4" pulley on gear box

Rate of feed (lbs./hr.) - whilst firing 18.0 - average during run - 9.0

Heat release (therms/hr.) - 1.03 (average during run)

Air setting - inlet damper 3/12 open - flow damper 8/12 open.

CO₂ (common range) 5 1/2 - 6 1/2%

CO₂ (maximum) 6 1/2%

Warm Air Temperature (common range) - 150° - 250° F.

 " " " (maximum) 275° F.

Flue Temperature (common range) 300° - 660° F.

 " " (maximum) 720° F.

Weather notes +30° to +50°

Combustion bed temperature (thermocouple) 2035°F.

Fly ash heavy deposit

Combustible matter in refuse 0.4%

 " " " " (as % of coal burned) 0.03%

Smoke notes - no smoke observed from chimney during either off or on periods.

Interruptions - none.

Clinkers removed 4 times during run.

Notes re clinkering and fire-bed - this coal exhibited no tendency to build up when using this air setting. The clinkers formed comprise the majority of the refuse except for a rather heavy deposit of fly-ash which settled out on the hearth area. The clinkers were large, hard, and brittle but showed no tendency to clog the tuyere area of the retort. This coal appeared to burn farther down into the retort than did other coals tested. In this 48 hour run, however, the tuyeres exhibited no evidence of being burned, although this factor undoubtedly might become

serious if this coal were used over longer periods of time. The clinkers apparently were easily pushed out of the fire on to the hearth area, and caused no trouble from unburned coal piling up on top of the clinker ring. The clinkers formed were dense and had an apparent specific gravity of 1.87 and a cell space of 34%. The hard chunks of clinker that formed caused the formation of blow holes in the fire-bed, hence the CO₂ in the flue gas was lower than usual. Irregularities in operation due to these hard chunks of clinker were also responsible for exposure of the tuyeres to the fire, and were the result of an ash which was too easily fusible.

Notes re fly-ash - Although the sizing of this coal was satisfactory for the underfeed, yet the fly-ash was excessive. It was noted that small particles popped off the larger lumps of coal in the combustion bed, and that these small particles were carried out of the combustion bed by the combustion gases. The shattering of the coal surface may be caused by the rapid escape of the high volatile matter content of this coal. As a result of the coal burning down inside the retort, instead of on top of the retort, this coal does not get as long a preheat as other coals do in the underfeed stoker. As a consequence there is a large amount of volatile matter still in the coal when it reaches the intensely hot fire-bed. This is driven off very rapidly and shatters the structure of the coal lump. This shattering, especially on the surface, causes excessive fly-ash.

An interesting feature in the combustion of this particular coal is the formation of 'cauliflower cokes' when the coal is heated quickly, even though this coal is classed as non-coking. The explosive escape of the high volatile matter content, causes the lump of coal to pop open, forming a coke particle which resembles a piece of cauliflower.

(b) In the Overfeed Stoker.

Periodicity	2' on 58' off
Run number	55
Length of run	23 hrs. 15 min.
Weight of coal burned	14 lbs.
Rate of feed	slow
" " " (lbs./hr.) - whilst firing -	18.0 - average during run - 0.6
Heat release (therms per hr.)	0.07 (average during run)
Air setting	8/12
CO ₂	no record
Warm air temperature	steady
Flue temperature (common range)	140 - 180° F.
" " (maximum)	190° F.
Weather notes	+20 to +40° F.
Combustion bed temperature	No record
Fly-ash	heavy deposit
Refuse	8.0%
Combustible matter in refuse	20.7%
" " " " (as % of coal burned)	1.3%
Smoke notes -	some smoke at beginning of 58' off period.
Temperature sensitive paint numerals -	1 and 2 changed color.
Interruptions	none
Clinker troubles	none

Notes re % combustible in refuse - this per cent was higher than usual, owing to the tendency of this coal to form cauliflower cokes, which drop into the ash pit unburned in this slow rate of operation. At this 2' on 58' off rate the combustion bed temperature is too low to allow complete combustion of these coke particles.

General notes re performace of this coal at 2' on 58' off periodicity - this coal gave a satisfactory stay-alight fire. The flue temperature record shows quick response by the fire-bed to stoker operation. No clinkers were noted in the refuse. There was very little tendency to burn back into the auger tube. Both fly-ash and combustibile matter in the refuse were higher than usual.

B. Summary Report of All Tests in the Underfeed Stoker.

In the following summary report of tests the main criteria used in judging the performance of a coal in the underfeed stoker must necessarily be the clinkering characteristics of the ash, the ash content of the coal and the tendency toward 'coke-tree' formation. Dustiness and excessive fly-ash in these tests should not be allowed to condemn a coal because dustiness can be eliminated by screening and oiling, while fly-ash usually can be kept within reasonable limits by proper coal sizing. Even if a properly sized coal does produce a larger than normal amount of fly-ash, the coal cannot be censured too much if it has a moderately low ash and the required clinkering properties. Also the inability of a coal to stay alight at any particular hold-fire periodicity, e.g., 2' on 58' off rate, need not condemn a coal because, by a simple adjustment on the hold-fire control of a household stoker, a periodicity can be chosen which will give a satisfactory stay-alight fire. A high-rank coal will require a longer on period than a lower rank coal. The response to stoker operation by a coal will also be dependent upon the rank of the coal, the higher rank coals being slow to respond and the lower rank, i.e., free-burning coals, being quick to respond. But all this can be provided for in the adjustment of the stoker for any particular coal.

A coal which produces excessive smoke in the underfeed stoker cannot be regarded as a suitable coal, but slight smokiness, particularly just at the beginning of an off period, cannot be given much weight in the adverse criticism of the coal. Three smoky coals were tested and in each case the coal was adversely criticized for its excessive smokiness, but in these cases the excessive smoke was accompanied by other more important disqualifying factors, thus, the ash was infusible, and strong 'coke-trees' were produced.

It should be noted that, even though a coal sample showed satisfactory clinkering properties, it does not follow that another consignment from the same mine but with notably higher or lower ash content would also show satisfactory clinkering properties. The reverse situation also applies.

In summary, a coal is judged unsatisfactory if the refuse does not clinker suitably, if the ash content is considerably in excess of one pound of ash per therm, and if strong 'coke-trees' are formed. Excessive smoke is liable to accompany the formation of strong 'coke-trees' and will thus add adverse criticism to a coal already judged unsatisfactory.

601/44

Insufficient coal was received for a complete test. Indication from the runs made showed this coal unsatisfactory in that clinkers were very bulky and caused a dirty fire.

602/44

This coal did not clinker freely enough and the percentage of ash was too high. Its performance was unsatisfactory.

603/44

Clinkering was good but the coal had too large a percentage of ash to permit this coal being rated as satisfactory.

604/44

Clinkering was insufficient to maintain a satisfactory combustion bed; and the ash percentage was too high. This coal was unsatisfactory.

605/44

This coal was dusty in handling; a run was made on an oiled portion and trouble from dust was then found to be negligible. Fly-ash was excessive in both cases. Clinkering was not entirely satisfactory in that the clinkers were too dense and formed in hard chunks; this allowed the tuyeres of the retort to be exposed to the combustion bed. The performance of this coal was not satisfactory.

606/44

This coal, a coking Kentucky Elkhorn coal supposedly widely sold in Winnipeg as an underfeed stoker fuel, proved poorly adapted for use in this underfeed stoker for three reasons: the ash was infusible; the 'coke-tree' formation was too strong to be broken up by the movement of coal through the combustion bed; and this coal was excessively smoky, since dense black smoke issued from the chimney in both on and off periods. This coal was definitely unsatisfactory.

607/44

This coal clinkered satisfactorily but the percentage of ash was too high. Blow holes developed in the fire-bed soon after clinker removal and the CO₂ recorder then showed a drop from 10% to 4% of CO₂ in the flue gas. The fly-ash deposit was larger than usual. The performance of this coal was unsatisfactory.



608/44

This coal was too freely clinkering to be satisfactory. A flat doughnut-shaped plate of dense, non-porous clinker formed in the hot fire following clinker removal; this clinker covered the entire tuyere area, and blocked off the air supply to the fresh coal above the clinker ring.

609/44

This coal was also too freely clinkering to give a satisfactory performance. The same remarks as for 608/44 apply here.

610/44

The ash of this coal was infusible and produced only a few small clinkers; this coal was therefore unsatisfactory. Chemical treatment with technical $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ gave a good clinker and the coal was then satisfactory. Experiments on this chemical treatment are described in a later section.

611/44

This coal was too freely clinkering and gave the same clinker trouble as described for 608/44. Performance was unsatisfactory.

612/44

Clinkers produced were porous and bulky; clinkering was sufficient to keep the fire-level down to a reasonable depth if clinkers were removed often enough. However the ash content of this coal was too high and for this reason clinker removal was required too often. This coal was unsatisfactory.

614/44

Clinkering and ash percentage were satisfactory, but clinkers and fly-ash were bulky. The over-all performance of this coal was not entirely satisfactory.

616/44

The ash of this coal was infusible and no clinkers were formed, and thus the coal was unsatisfactory. Chemical treatment with technical $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ and Ferrite Yellow gave satisfactory clinkering. Blending with a low rank coal also gave good clinkering and satisfactory operation. This work on blending and chemical treatment is discussed in detail in later chapters.

617/44

This coal produced very strong 'coke-trees' which were too strong to be broken by movement of the combustion bed. The percentage of ash was moderate but the ash was infusible. A dense, black smoke issued from the chimney during the first part of an off period, but smokiness was not as bad during the on periods. This coal was unsatisfactory. Several attempts were made to reduce the coking tendency and to improve clinkering by blending. This work will be described in a later chapter.

621/44

The ash content of 621/44 was very high. The coal produced 'coke-trees' and gave no clinker. The performance of this coal was unsatisfactory. It was smoky but not as much so as 617/44. Blending experiments in an attempt to reduce coking and improve clinkering for this coal are discussed later.

C. Summary Report of Tests in the Overfeed Stoker.

For the overfeed stoker the main criterion used in judging the performance of a coal must necessarily be the clinkering nature of the ash since no coals were tested that were not free-burning. Dustiness and excessive fly-ash should not condemn a coal for the overfeed stoker if

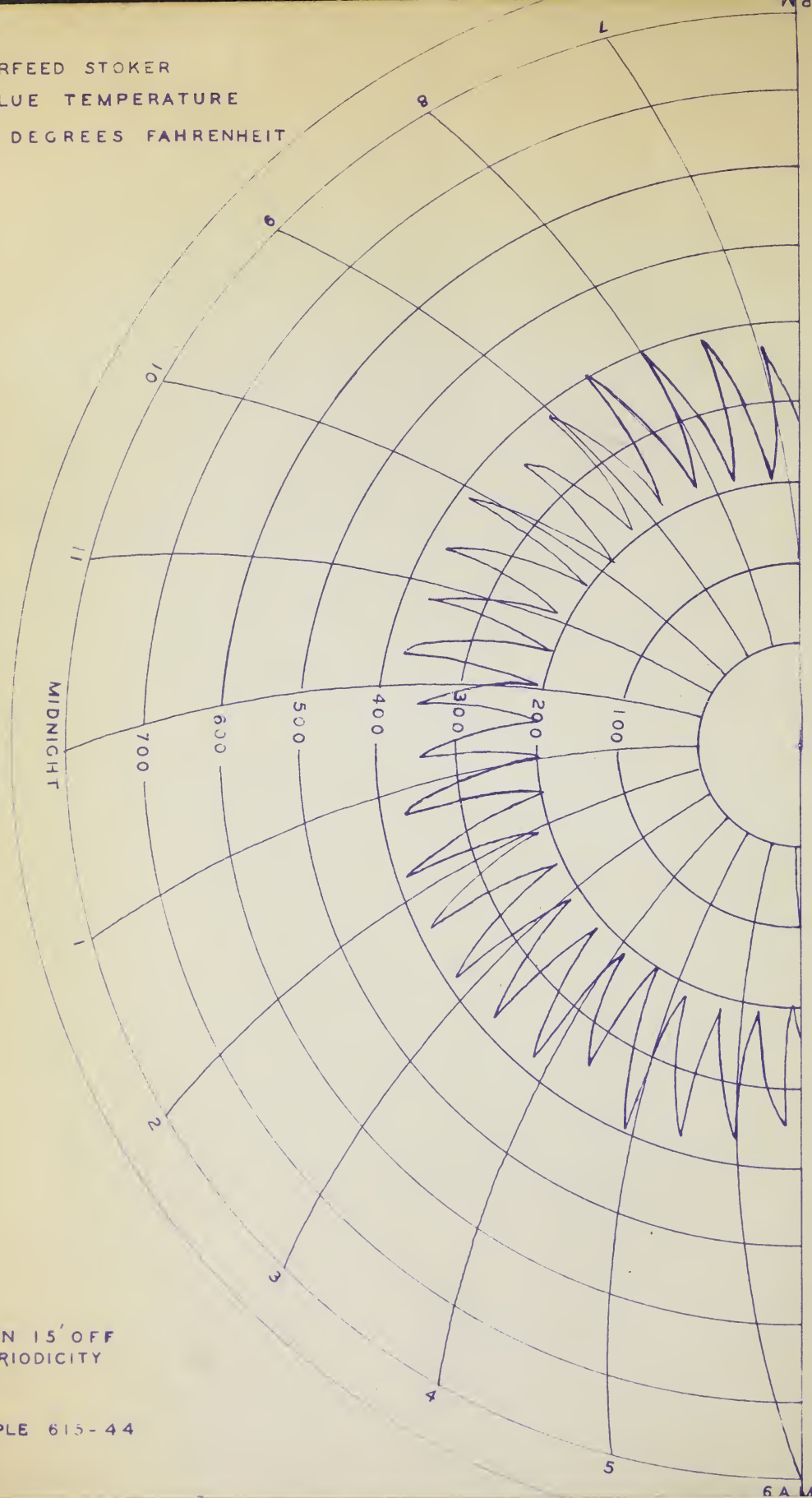
this coal shows no tendency toward clinker trouble. Smoke will not be excessive in the overfeed stoker if only free-burning coals are used although those free-burning coals, close to the higher rank coals, may produce slight smoke in the overfeed especially at the beginnings of off periods; this slight smoke is considered relatively unimportant in judging the performance of a coal.

Accordingly, in the following summary report of coals tested in the overfeed stoker, a coal will only be judged unsatisfactory if it gives clinker trouble. Wherever fly-ash and/or dust are excessive, appropriate notes are given and the probable reasons are noted.

Figures VIII, IX, X and XI contrast the flue and warm air temperature records for satisfactory and unsatisfactory operation in the ~~under~~^{OVER}feed stoker at the 15' 'on 15' off periodicity. Coal 615/44 gave no clinker trouble; the temperature records show an even and regular rise and fall throughout the twelve hour period illustrated. Coal 613/44 was unsatisfactory in that a 'clinker-bridge' was produced with a resultant large drop in flue temperature and in warm air temperature. When the 'clinker-bridge' formed the coal fed on to the retort passed over and around the clinker and dropped into the ash-pit almost completely unburned. 9.1% of the coal fed on to the retort gave no heat release in the furnace. This percentage would have been much higher if it were not for the fact that the 'clinker-bridge' did not form until approximately eighteen hours of the full twenty-four hours of the run had elapsed.

FIGURES VIII and IX

OVERFEED STOKER
FLUE TEMPERATURE
DEGREES FAHRENHEIT



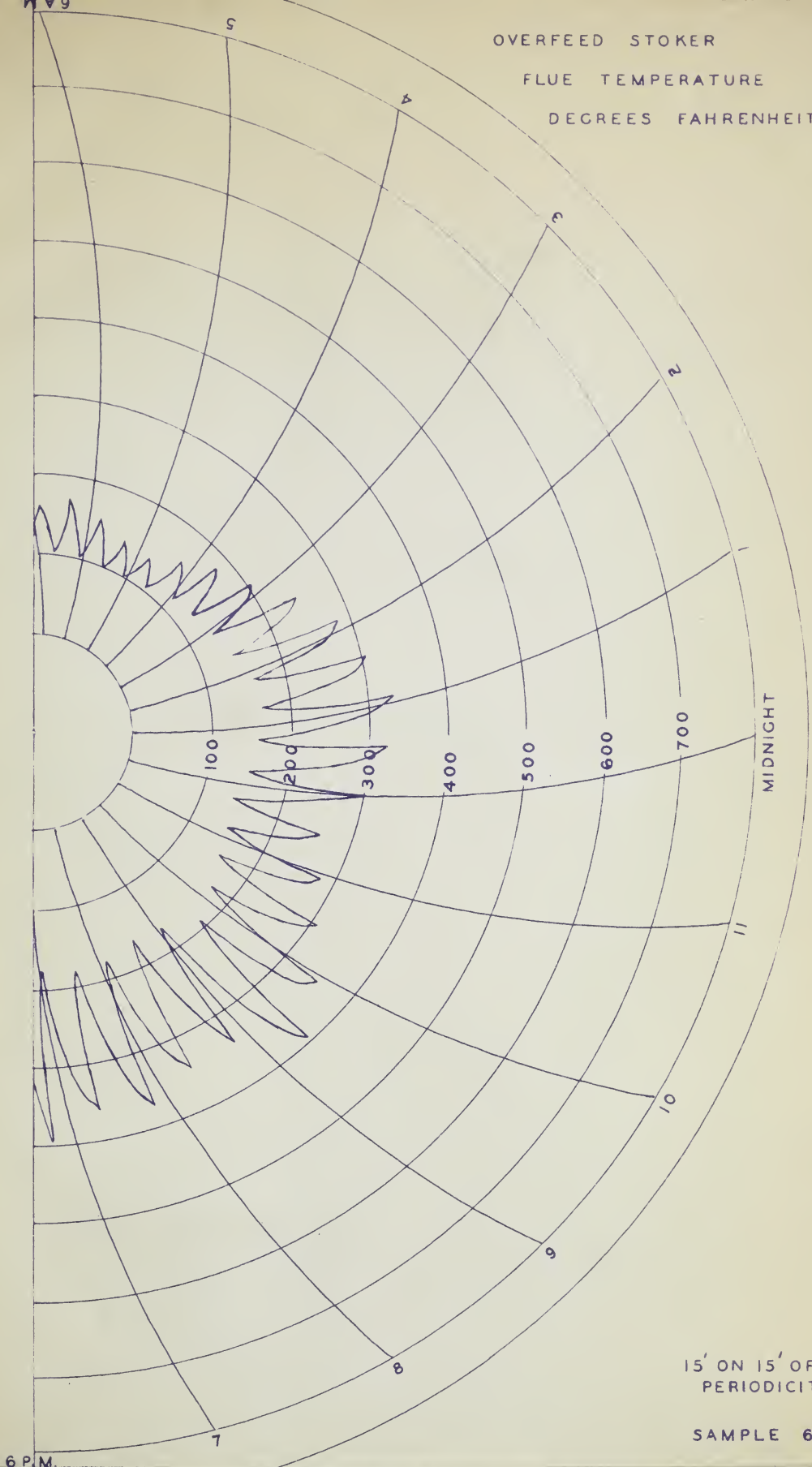
15' ON 15' OFF
PERIODICITY

SAMPLE 615-44

OVERFEED STOKER

FLUE TEMPERATURE

DEGREES FAHRENHEIT



15' ON 15' OFF
PERIODICITY

SAMPLE 613-44

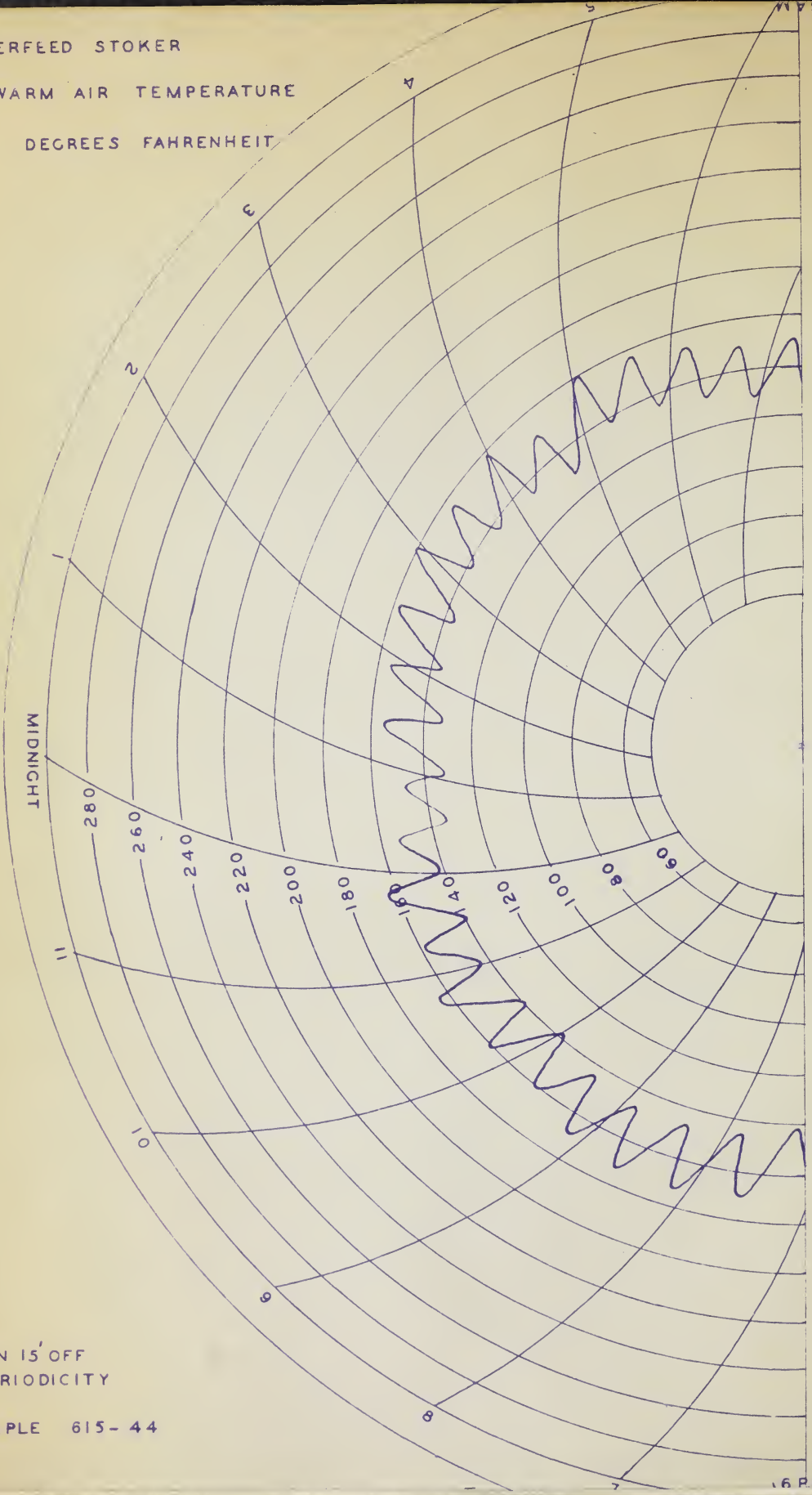
6 P.M.

FIGURE X and XI

OVERFEED STOKER

WARM AIR TEMPERATURE

DEGREES FAHRENHEIT



15' ON 15' OFF
PERIODICITY

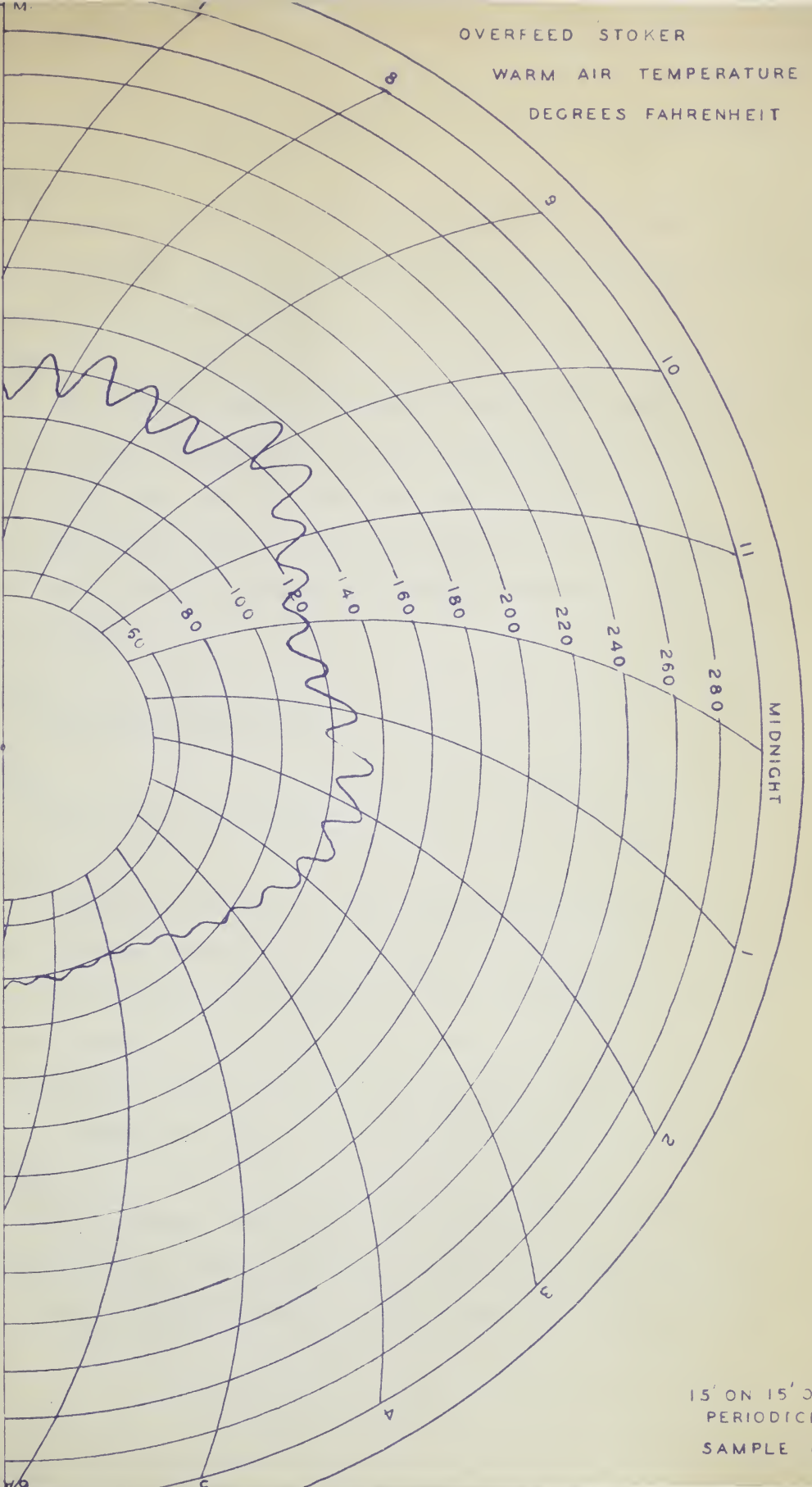
SAMPLE 615-44

16 PM

OVERFEED STOKER

WARM AIR TEMPERATURE

DEGREES FAHRENHEIT



15' ON 15' OFF
PERIODICITY

SAMPLE 613-44

601/44

Slight smoke was noted at the beginning of the off periods. There was not sufficient coal for a complete test, but the tests made indicated that this coal was satisfactory.

602/44

This coal, taken from the University power house, produced excessive fly-ash probably because of its high ash content and the large amount of slack in the coal. The first test runs showed too high a loss in combustibile in the refuse. Improved settings of air and coal feed on a fresh sample gave lower losses. The general performance of the coal was satisfactory.

603/44

This coal was satisfactory.

604/44

This coal was satisfactory.

605/44

Although the performance of this coal was satisfactory, it was noted that the combustibile matter in the refuse increased as the rate of stoker operation decreased. The explanation - the poor combustion at the slow rate of combustion - has already been discussed. This coal was dusty and produced a large amount of fly-ash in spite of its low ash content and good sizing. Slight smoke was noted at the beginning of each off period.

607/44

This coal gave a satisfactory performance; however, its ash content was high and this probably accounted for the greater than normal amount of fly-ash. Slight smoke was noted at the beginning of each off period.

608/44

A 'clinker-bridge' formed during the 15' on 15' off rate of operation. Fly-ash was excessive, probably because of the large amount of slack in the coal. This coal was unsatisfactory.

609/44

A 'clinker-bridge' formed during both the 15' on 15' off and 10' on 30' off runs. This coal was a power house sample and contained considerable slack. For this reason sparking and fly-ash were excessive. Performance of this coal was unsatisfactory.

611/44

A 'clinker-bridge' formed during the 15' on 15' off run. Fly-ash was exceptionally low probably due to close sizing of the coal sample. Performance of this coal was unsatisfactory.

612/44

Some clinkering trouble was noted in the 15' on 15' off and 10' on 30' off runs. An actual 'clinker-bridge' was not observed but large pieces of porous clinker and considerable unburned material were noted in the refuse, and the flue and warm air temperatures were irregular. The performance of this coal therefore cannot be regarded as satisfactory.

613/44

A 'clinker-bridge' formed in the 15' on 15' off and 10' on 30' off runs. This coal was poorly sized and contained considerable slack; the fly-ash deposit in the flue-receptacle was excessive. This coal was unsatisfactory.

614/44

This coal was satisfactory.

615/44

This coal was satisfactory.

618/44

This coal was satisfactory.

619/44

This coal was satisfactory.

620/44

This coal was satisfactory.

622/44

This coal was extremely wet when received at the laboratory. In the first test run, the coal, a power plant sample, formed a bridge in the hopper that interrupted the feeding of coal to the retort. A portion of this sample was dried and another run was made. The dried coal did not bridge in the hopper but clinker trouble was encountered during the 15' on 15' off run - a 'clinker-bridge' formed. This coal was unsatisfactory.

D. Compilation of Results

TABLE IV

Samples by Classification and Areas

Classification	Area		Area Outputs (1943) - short tons	Sample Numbers (all of 1944)
Semi-anthracite	Cascade	K 7	343,000	610, 616
Medium Volatile Bituminous	Crowsnest	K10	2,000,000	621
	Mt. Park	K 3	843,000	617
High Volatile A Bituminous	Kentucky	-	-	606
High Volatile C Bituminous	Coalspur	B 3	713,000	612
	Lethbridge	B 9	579,000	601, 607
	Saunders	B 4	65,000	605
	-	-	-	602
Subbituminous B	Brooks	B14	30,000	615
	Carbon	E 8	68,000	620
	Drumheller	E10	1,839,000	604, 609
	Edmonton	E 2	457,000	603
	Pembina	E 1	54,000	614
	Taber	B12	21,000	619
Subbituminous C	Camrose	E 4	64,000	618
	Edmonton	E 2	457,000	622
	Redcliff	B22	28,000	613
	Sheerness	E 9	59,000	611
	Tofield	E 3	85,000	608

TABLE V

Coal Analyses - As Received Basis

Sample No.	Area	Proximate Analysis				Ultimate Analysis						Cal. Value B.t.u./lb.	V.M. F.C.	Per Therm	
		Moist. %	Ash %	V.M. %	F.C. %	C %	H %	Ash %	S %	N %	O %			Coal Lbs.	Ash Lbs.
601	B 9	9.8	11.4	33.4	45.4	61.90	5.45	11.4	0.85	1.6	18.8	10,910	1.35	9.17	1.05
602	(?)	12.1	17.0	27.2	43.7	59.05	4.75	17.0	0.30	0.8	18.1	10,150	1.60	9.86	1.68
603	E 2	21.8	11.4	27.4	39.4	50.10	5.90	11.4	0.30	1.0	31.3	8,660	1.45	11.6	1.32
604	E 10	17.8	11.0	28.8	42.4	55.15	5.75	11.0	0.50	1.2	26.4	9,450	1.45	10.6	1.16
605	B 4	8.4	8.8	32.1	50.7	66.00	5.10	8.8	0.60	1.0	18.5	11,430	1.60	8.75	0.77
606		2.8	4.7	34.8	57.7	79.05	5.40	4.7	0.85	1.2	8.8	14,050	1.65	7.07	0.33
607	B 9	11.1	13.5	31.9	43.5	58.50	5.35	13.5	0.65	1.3	20.7	10,260	1.35	9.75	1.32
608	E 3	26.0	6.2	28.8	39.0	51.25	6.40	6.2	0.45	1.0	34.7	8,750	1.35	11.4	0.71
609	E 10	19.2	8.5	29.5	42.8	54.35	5.80	8.5	0.65	1.2	29.5	9,400	1.45	10.6	0.90
610	K 7	0.6	7.6	13.1	78.7	82.85	4.10	7.6	0.65	1.6	3.2	14,180	6.0	7.06	0.54
611	E 9	24.6	7.2	29.5	38.7	50.35	6.15	7.2	0.50	0.9	34.9	8,530	1.30	11.7	0.84
612	B 3	9.1	14.4	30.1	46.4	60.25	4.65	14.4	0.20	0.5	20.0	10,210	1.55	9.80	1.41
613	B 13	19.9	14.8	26.5	38.8	48.75	5.50	14.8	0.65	0.8	29.5	8,260	1.45	12.1	1.79
614	E 1	20.3	8.9	28.0	42.8	53.20	5.65	8.9	0.45	0.7	31.1	8,920	1.55	11.2	1.00
615	B 14	14.3	16.4	28.8	40.5	52.65	5.35	16.4	0.50	1.3	23.8	9,100	1.40	11.0	1.80
616	K 7	0.5	10.5	11.8	77.2	81.05	3.85	10.5	0.50	1.5	2.6	13,790	6.55	7.25	0.76
617	K 3	1.8	12.9	26.0	59.3	75.05	4.45	12.9	0.30	1.0	6.3	13,100	2.30	7.64	0.99
618	E 4	26.0	7.6	26.9	39.5	49.60	6.35	7.6	0.45	1.0	35.0	8,470	1.45	11.8	0.90
619	B 12	17.9	13.8	27.7	40.6	52.05	5.55	13.8	1.0	1.2	26.4	8,990	1.45	11.1	1.54
620	E 8	16.3	12.1	26.8	44.8	55.50	5.35	12.1	0.55	0.9	25.6	9,530	1.65	10.5	1.27
621	K 10	1.4	18.5	23.9	56.2	69.35	4.20	18.5	0.95	1.0	6.0	12,060	2.35	8.30	1.53
622	E 2	26.8	14.0	24.2	35.0							7,510	1.45	13.3	1.86
616+618			9.8									12,460		8.03	0.79

TABLE VI

Fuel Losses in Refuse from Combustion

Sample	% Ash A.R.	Overfeed Stoker			Underfeed Stoker		
		Run	% combustible in refuse	combustible as % of coal fired	Run	% combustible in refuse	combustible as % of coal fired
601	11.4	A	10.7	1.2	E	1.6	0.2
		B	14.7	1.7	G	3.2	0.4
		C	3.0	0.3			
602 (Original)	17.0	A	23.8	4.0	E	0.8	0.1
		B	23.3	4.0	E'	0.8	0.1
		C	7.0	1.2	F	0.6	0.1
					G	0.1	0.02
					H	0.2	0.03
602 (New sample)	14.8	A	16.4	2.4			
		B	12.4	1.8			
		C	11.3	1.7			
603	11.4	A	7.2	0.8	E	0.9	0.1
		B	3.4	0.4	F	0.3	0.03
		C	3.0	0.3	G	0.1	0.01
604	11.0	A	6.5	0.7	E	2.2	0.2
		B	4.8	0.5	E'	1.5	0.2
		C	7.5	0.8	E''	0.9	0.1
		D	4.8	0.5	F	2.7	0.3
605	8.8	A	12.8	1.1	E	0.4	0.04
					E		
		B	15.4	1.4	oiled	1.2	0.1
		C	20.7	1.8	F	0.5	0.04
					G	0.4	0.04
607	13.5				G		
					oiled	0.6	0.05
		A	6.9	0.9	E	2.1	0.3
		B	7.6	1.0	E'	1.7	0.2
		C	4.4	0.6	F	1.3	0.2
608	6.2				G	0.9	0.1
		A	68.0	4.2	E	0.3	0.02
		B	29.3	1.8	F	0.2	0.01
609	8.5	C	5.6	0.3	G	0.8	0.05
		A	41.3	3.5	E	2.4	0.2
		B	54.5	4.6	F	1.6	0.1
		C	17.0	1.4	G	1.1	0.09

TABLE VI (cont'd)

Fuel Losses in Refuse from Combustion (cont'd)

Sample	% Ash A.R.	Run	Overfeed		Run	Underfeed	
			% combustible in refuse	combustible as % of coal fired		% combustible in refuse	combustible as % of coal fired
611	7.2	A	46.0	3.3	E G	1.2 0.5	0.09 0.04
612	14.4	A B C	31.2 26.1 12.2	4.5 3.8 1.8	E E'	4.5 2.5	0.6 0.4
613	14.8	A B C	61.6 46.0 36.4	9.1 6.8 5.4			
614	8.9	B C	19.7 4.0	1.8 0.4	E E' F	0.03 0.1 0.1	0.00 0.01 0.01
615	16.4	A B C	25.0 22.7 4.7	4.1 3.7 0.8			
616					135	4.2	
618	7.6	A B C	6.2 3.4 5.7	0.5 0.3 0.4			
$\frac{1}{4}$ 618+	9.8				E F	4.1 4.5	0.4 0.4
$\frac{3}{4}$ 616							
619	13.8	A B C	33.6 30.1 25.8	4.6 4.2 3.6			
620	12.1	A B C	22.1 17.7 17.6	2.7 2.1 2.1			

NOTES: A - 15' on 15' off overfeed

B - 10' on 30' off "

C - 2' on 58' off "

D - 4' on 56' off "

E - 15' on 15' off underfeed

F - 10' on 30' off "

G - 2' on 58' off "

H - 4' on 56' off "

E', E'' and F' refer to repeat runs.

TABLE VII

Ash Fusion Temperatures

Sample	Area	% Ash A.R.	I.D. °F.	S.T. °F.	F.T. °F.	Softening Interval	Fluid Interval
601	B 9	11.4	2220	2280	2390	60	110
602	(?)	17.0	2235	2360	2505	125	145
603	E 2	11.4	2215	2300	2480	85	180
604	E 10	11.0	2215	2235	2350	20	115
605	B 4	8.8	2145	2235	2340	90	105
606	Ken- tucky	4.7	-	-	-	-	-
607	B 9	13.5	2235	2290	2415	55	125
608	E 3	6.2	2055	2100	2145	45	45
609	E 10	8.5	1940	1990	2130	50	140
610	K 7	7.6	+2685	+2685	+2685	-	-
610+ FeSO ₄ ·7H ₂ O		8.3	2385	2440	2520	55	80
611	E 9	7.2	2210	2235	2360	25	125
612	B 3	14.4	2100	2175	2280	75	105
613	B 13	14.8	2100	2235	2505	135	270
614	E 1	8.9	2350	2450	2565	100	115
615	B 14	16.4	2235	2360	2550	125	190
616	K 7	10.5	+2685	+2685	+2685	-	-
617	K 3	12.9	2460	2595	+2685	135	-
618	E 4	7.6	2055	2145	2370	90	225
619	B 12	13.8	2280	2380	2550	100	170
620	E 8	12.1	2220	2355	2550	135	195
621	K 10	18.5	+2685	+2685	+2685	-	-

TABLE VII (cont'd)

Ash Fusion Temperatures (cont'd)

Sample	Area	% Ash A.R.	I.D. °F.	S.T. °F.	F.T. °F.	Softening Interval	Fluid Interval
622	E 2	14.0	2340	2380	2530	40	150
602F	(?)	7.3	2245	2325	2505	80	180
605F	B 4	4.7	2205	2245	2290	40	45
607F	B 9	7.7	2250	2265	2390	15	125
616+ Ferrite Yellow		12.4	2280	2370	2670	90	300
616+618		9.8	2530	2685	+2685	155	-
601/45	E ₁₀	10.2	1915	2090	2350	1.75	260

I.D. - Initial Deformation

S.T. - Softening Temperature

F.T. - Fluid Temperature

TABLE VIII

Ash Analyses

Sample	Area	% Ash A.R.	SiO ₂	Al ₂ O ₃	SO ₃	Fe ₂ O ₃	CaO	Unaccounted for	Na ₂ O	K ₂ O
601	B 9	11.4	52.64	25.59	4.18	5.39	9.05	~~0.66~~ ~~8.16~~	2.13	0.36
602	(?)	17.0	60.45	23.30	2.29	3.59	9.50	~~-0.01~~ ~~0.97~~	0.47	0.41
603	E 2	11.4	54.03	24.51	4.89	4.07	8.19	~~-0.70~~ ~~4.71~~	4.67	0.34
604	E 10	11.0	53.28	25.62	2.90	6.34	5.91	~~1.64~~ ~~6.95~~	4.02	0.29
605	B 4	8.8	42.78	23.26	6.14	8.71	15.51	~~0.98~~ ~~3.60~~	1.69	0.93
607	B 9	13.5	52.89	27.10	4.54	5.14	7.51	~~0.07~~ ~~2.82~~	2.00	0.75
608	E 3	6.2	28.69	29.79	10.57	5.13	18.94	~~1.63~~ ~~6.98~~	4.75	0.50
609	E 10	8.5	40.14	20.96	10.15	12.23	9.42	~~1.88~~ ~~7.10~~	4.06	1.16
610	K 7	7.6	51.35	37.46	1.33	8.38	1.30	~~-0.46~~ ~~0.10~~	0.00	0.64
611	E 9	7.2	38.44	24.39	8.79	5.89	17.05	~~2.80~~ ~~6.44~~	2.17	0.47
612	B 3	14.4	53.93	18.46	2.25	3.30	19.22	~~1.04~~ ~~2.94~~	1.41	0.39
613	B 13	14.8	46.27	24.63	7.63	5.27	7.99	~~2.32~~ ~~6.21~~	5.15	0.74
614	E 1	8.9	41.32	29.68	3.54	4.55	18.65	~~1.76~~ ~~2.28~~	0.05	0.45
615	B 14	16.4	55.88	25.94	4.48	2.97	3.96	~~2.42~~ ~~6.77~~	3.85	0.50
616	K 7	10.5	58.47	33.41	2.22	2.64	1.96	~~-0.38~~ ~~1.30~~	0.47	1.21
617	K 3	12.9	53.96	29.94	2.20	2.20	4.62	~~0.57~~ ~~2.08~~	0.76	0.75
618	E 4	7.6	38.10	28.91	7.50	3.14	13.25	~~2.58~~ ~~9.10~~	5.94	0.58
619	B 12	13.8	49.41	28.70	5.44	4.14	5.56	~~4.07~~ ~~6.76~~	1.87	0.77
620	E 8	12.1	50.13	26.51	3.16	4.10	9.48	~~2.87~~ ~~6.62~~	3.35	0.40
621	K 10	18.5	55.89	33.66	1.95	6.99	1.94	~~-1.06~~ ~~0.43~~	0.15	0.48
622	E 2	14.0	51.56	30.47	2.59	2.00	8.05	~~2.34~~ ~~5.33~~	2.59	0.40

TABLE VIII (cont'd)

Ash Analyses (cont'd)

Sample	Area	% Ash A.R.	SiO ₂	Al ₂ O ₃	SO ₃	Fe ₂ O ₃	CaO	Unaccounted for	Na ₂ O	K ₂ O
602F	(?)	7.3	60.28	24.73	3.86	3.67	6.55	~~0.43~~ 0.91	0.97	0.35
605F	B 4	4.7	39.53	28.27	6.24	10.70	10.50	~~1.81~~ 4.76	2.48	0.47
607F	B 9	7.7	48.47	28.43	3.42	5.66	8.67	~~2.11~~ 5.35	2.45	0.29
616+ Ferrite Yellow		12.4	49.5	29.9	1.9	15.7	1.9	1.1		
616+618		9.8	53.4	32.3	3.6	2.8	4.8	3.1		
601/45	E ₁₀	10.2	54.28	21.04	4.73	3.90	7.57	3.86	3.87	0.81

Method: Shortened Method of Ash Analysis - British Standard Methods
for the Analysis of Coal Ash and Coke Ash. No. 686-1936.

Time was not available for the determination of alkalis but it is hoped
to make these later.

TABLE IX

Specific Gravity and Cell Space in Clinkers

Coal	Stoker	True Specific Gravity	Apparent Specific Gravity	% Cell Space
602	U	2.59	1.27	51
603	U	2.68	1.14	57
604	U	2.54	1.15	55
605	U	2.84	1.87	34
607	U	2.58	1.24	52
608	O	2.88	2.06	29
609	U	2.94	1.65	44
609	O	2.88	1.73	40
609	O	2.81	1.73	39
*610-A mixture	U	2.43	1.57	35
*610-B mixture	U	2.75	1.69	39
611	U	2.90	1.97	32
611	O	2.89	1.83	37
*612 E'	U	2.73	1.49	45
*612 E''	U	2.68	1.73	35
613	O	2.60	1.65	37
614	U	2.88	1.90	34
*Char	U	2.75	1.68	39
*616+618 - C mixture	U	2.55	1.59	38
*616+618 - D mixture	U	2.59	1.57	39
*616 - E mixture	U	2.61	1.72	34
*617+618 - F mixture	U	2.60	1.47	43

See next page for notes re. coals marked *.

Notes re. Table IX:

- (1) All clinker samples taken from 15' on 15' off.
- (2) Ratios quoted are $\frac{\text{SiO}_2 + \text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$
- (3) 610 - A mixture - ratio = 7.7
- (4) 610 - B " " = 6.1
- (5) 612 E' - 13.7 lbs. coal per hour continuous operation.
- (6) 612 E" - 18.4 " " " " " "
- (7) Char - from Beverley coal by carbonization.
- (8) 616+618 - C mixture - blend of $1/2(616) + 1/2(618)$
- (9) 616+618 - D " " " $3/4(616) + 1/4(618)$
- (10) 616 - E mixture - ratio = 5 and CaO = 6%
- (11) 617+618 - F " - blend of $1/2(617) + 1/2(618)$

Fly-ash

The stoker tests of twenty-two coals ranging in rank from semi-anthracite to subbituminous C showed that:

(a) All coals produce fly-ash and the main trouble experienced is the blocking of flues and the insulation of heat transfer surfaces. The amount of fly-ash that must be expected under the best conditions is large enough to require that a furnace and its flue pipes be cleaned at least once a year (usually at the end of the heating season).

(b) The normal amount of fly-ash to be expected from a high ash coal is larger than that for a low ash coal. Clinkering of the ash may reduce the amount of fly-ash produced.

(c) Excessive fly-ash is likely to be produced if the coal is improperly sized. Slack sizes and the fracturing of oversize lumps in the auger tube are responsible for fly-ash in excess of the normal amount.

(d) Some coals, e.g., 605/44, produce excessive fly-ash regardless of their sizing. No method has been evolved for decreasing this inherent tendency of such coals to produce fly-ash.

(e) Oiling a coal to reduce dust does not reduce fly-ash.

(f) The loss in heat value in fly-ash is small for any coal but for lower rank coals it is smaller than for higher rank coals; burning particles of the former rank of coal blown out of the combustion bed are more likely to be completely burned than are particles of higher rank coals which have a higher ignition temperature and which are likely to go out as soon as they leave the combustion zone. The heat value of the fly-ash from lower rank coals is approximately half of that for higher rank coals; values were recorded ranging from 5000 to 10,000 B.t.u./lb. but the actual values varied not only with the rank of the coal but also with the place and manner of collecting the sample.

Combustion-bed Temperatures.

These temperatures were taken first with a thermocouple and second with an optical pyrometer. The results were not comparable since the former measured the temperature in the fire-bed and the latter on the surface of the fire-bed; neither method was satisfactory. Values were recorded with the thermocouple ranging from 1755 to 2310° F. and with the optical pyrometer from 1840 to 2600° F.

Photographs.

Sixteen photographs were taken through the door of the underfeed stoker in an endeavour to obtain a positive record of fire-bed conditions. These were amateur photographs taken without any special equipment, and the small amount of room between the furnace opening and the wall of the building would have made any more elaborate photography extremely difficult. The results obtained were not sufficiently informative to warrant inclusion in this report.

Photographs were also taken of a number of samples of clinkers but it was not found possible to distinguish photographically between different degrees of porosity.

STUDIES OF CLINKER FORMATION

A. Introduction.

As a result of this investigation moderately low ash content (below one pound of ash per therm.) and suitable clinkering have been specified as essential to the satisfactory operation of an underfeed stoker. Special studies were made in trying to improve the performance of some of the coals judged unsatisfactory. These studies included modification of the clinkering properties by chemical treatment and blending, and the effect of coal washing on the clinkering properties of the ash.

At this point a brief historical review is given of the published work on the fusibility and chemical composition of ash in relation to its clinkering properties.

The fusibility of an ash is usually determined in America by the standard A.S.T.M. method⁽⁷⁾ in a Melter's furnace on a small cone of ash mounted on a refractory base. In this method three temperatures are measured at which the ash cone shows different stages of deformation. These stages are: initial deformation, i.e., when the tip of the cone becomes slightly rounded; softening temperature, i.e., when the cone bends so that the tip touches the base or when the cone melts and becomes spherical in shape; fluid temperature, i.e., when the ash flows over the base. A variation often used in the Research Council laboratories is the cone series method. Instead of measuring the initial deformation, softening, and fluid temperatures for each ash in one run, a number of cones of different ashes are placed in the furnace and the furnace is heated to a definite temperature. Additional runs are then made at 45° F. temperature intervals above and below the first temperature. In this

way a cone series for each ash is obtained and the three deformation temperatures can be selected. This R.C.A. method eliminates the difficulty in the standard method of seeing the changes in the shape of the cone at high temperatures.

Cone series for four unsatisfactory coals and five satisfactory coals for the overfeed stoker are shown in Figure XII. The ash of the first four coals produced 'clinker-bridges'. No clinker troubles were experienced in the test runs with the last five coals.

The first five cone series in Figure XIII are of coals unsatisfactory for the underfeed stoker. The first two formed clinkers that were too dense, the third was not freely enough clinkering, the fourth produced no clinkers at all, while the fifth gave a very bulky clinker. The last four cone series in Figure XIII illustrate experiments described later on chemical treatment and blending of coals to modify clinkering properties.

Fieldner and Selvig⁽⁶⁾ divide coals into three classes of fusibility:

Class 1 - refractory ash, softening above 2600°F.

Class 2 - ash of medium fusibility, softening between 2200 and 2600°F.

Class 3 - easily fusible ash, softening below 2200°F.

Class 1 ashes are generally non-clinkering in furnaces while Class 3 ashes will usually form hard, glassy, non-porous clinkers. E. Schwartzman⁽²⁴⁾ says that ashes in Class 2 will clinker, but the amount of clinker will depend upon the distribution of mineral matter in the coal, the atmosphere to which the ash is exposed, the coal sizing, the rate of combustion, the extent to which the mineral matter in the coal becomes mixed with the fuel in the hottest region of the fuel bed, the coking characteristics of the coal, and other general conditions arising from the design of the furnace.

Sample No.

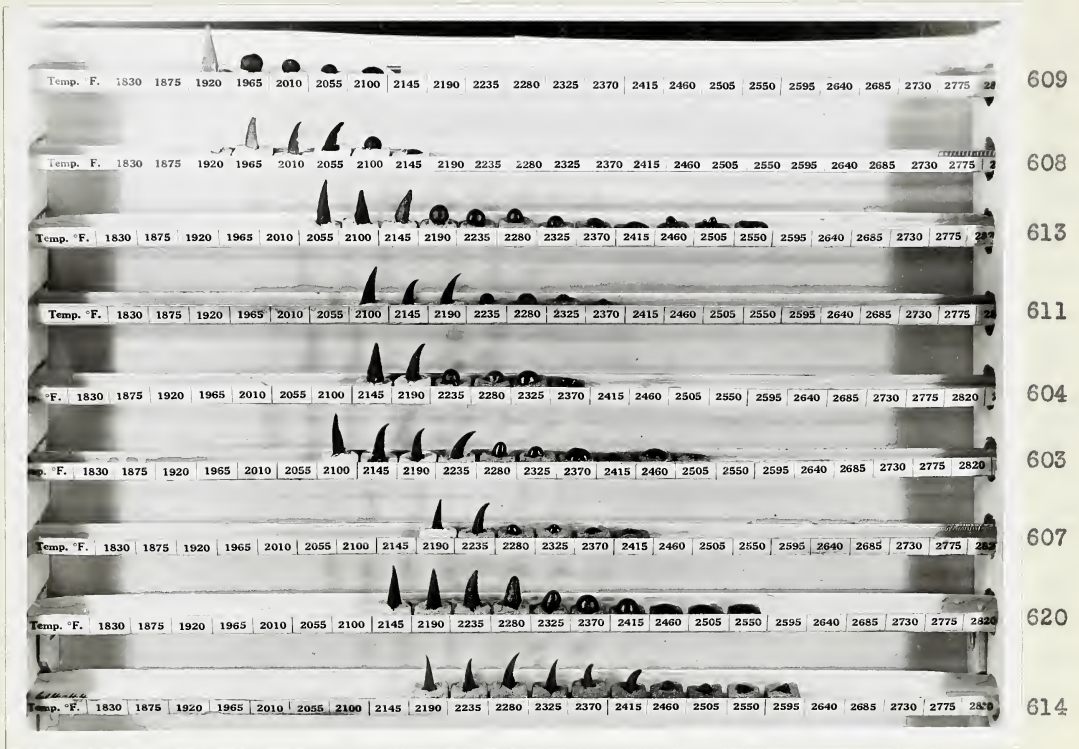


FIGURE XII - Cone Series of Ashes of Nine Coals Tested in the Overfeed Stoker.

Sample No.



FIGURE XIII - Cone Series of Ashes of Coals Tested in the Underfeed Stoker, Including Chemically Treated and Blended Fuels.

There is in fact only a rough proportionality between the clinkering of an ash in a fuel bed and the softening temperature of the ash as determined in the A.S.T.M. method. The softening temperature is determined in a mildly reducing atmosphere on an intimately mixed small quantity of finely ground pre-oxidized material, while in a furnace the mineral constituents of the ash are unevenly distributed and are exposed to other variable conditions of temperature, atmosphere and time. Under such conditions clinkering probably will take place in the form of an agglomeration of unfused particles cemented together by more fusible material, although clinkers sometimes may be formed through complete fusion of the ash in one locality of the furnace. The amount of clinkering will be dependent on the amount and viscosity of the low fusing material, and also upon the effect on the molten material of the incorporation therein of refractory matter.

It is apparent that unpredictable variable factors may cause a coal, placed in one of Fieldner and Selvig's classes, to exhibit clinkering properties dissimilar to its classification. In general, however, this classification can be used as a good working rule.

A beginning has been made by other workers in establishing relationships of the chemical analysis and fusibility of ash with clinker formation. As yet not enough work has been done on this problem to permit the prediction of the clinkering tendency of an ash from its ash analysis with a fair degree of certainty. This whole question is almost infinitely complex and is dependent upon the compilation of ash analyses which are tedious and costly. The chemical analyses of twenty-four ashes have been made for record although only a few were needed for the stoker investigation.

B. Effect of Chemical Treatment.

E. Schwartzman⁽²⁴⁾ in studying the suitability of coals for blowers found that where the CaO content was below 6%, if the ratio $\frac{\text{SiO}_2 + \text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$ is adjusted to between 4 and 6 by the addition of iron oxide or otherwise the ash will clinker satisfactorily. This principle was used in attempting to adjust the clinkering nature of three coals to suit the needs of the underfeed stoker. A summary of the work done follows.

The first coal used was a semi-anthracite coal from Cascade area, sample 610/44. Its ash softening temperature was +2635°F. and it produced only a few clinkers. The % ash was 7.6 and the ratio $\frac{\text{SiO}_2 + \text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$ was 10.6 with CaO content of 1.3%. Following Schwartzman's patent an iron compound was added to this coal to reduce the ratio.

Several trial runs were made using different ratios. In all runs powdered technical $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ was added to oiled coal and the mixture worked over for uniform distribution.

The oil in these runs was intended mainly to serve as an adhesive to hold the iron compound on the surface of the coal and to permit its uniform distribution, although oiling would be advisable in any case to provide a clean fuel for household stokers.

In the first trial run, with the coal treated to give a ratio of 5.0, the clinkers produced were satisfactory, being tough enough to allow for removal but porous enough to allow passage of air to the unburned coal above the clinker ring. To obtain this ratio of 5.0, 2.48 pounds of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ per 100 pounds of coal were required. The addition of 2.48 pounds of this iron compound increased the ash from 7.6% to 8.4% and decreased the calorific value from 14,180 B.t.u./lb. to 14,060 B.t.u./lb. In view

of the fact that a satisfactorily clinkered ash has a high density, the volume of ash removed from the furnace was less than would have been the case for an unfused or weakly fused ash.

It was desirable to use the least amount of iron possible in this chemical treatment; thus ratios of 6.1 and 7.7 were tried but clinkering was unsatisfactory.

The results of these runs are summarized in Table X.

TABLE X
Chemical Treatment of 610/44

	Original Coal	Chemically Treated Coal	Ash Analysis for original Coal		
Calorific value (B.t.u./lb.)	14,180	14,070	SiO ₂	%	51.4
Ash %	7.6	8.3	Al ₂ O ₃	%	37.5
Ash (pounds per therm)	0.54	0.59	SO ₃	%	1.3
Softening Temperature	+2685°F.	2440°F.	Fe ₂ O ₃	%	8.4
$\frac{\text{SiO}_2 + \text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$	10.6	5.0	CaO	%	1.3
Clinkering	nil	Very satis- factory			

Chemical treatment by adjustment of the ratio $\frac{\text{SiO}_2 + \text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$ was also used on another sample of Cascade area coal from the same mine as 610/44. This second sample - 616/44 - also had an infusible ash. Its ash content was higher (10.5% compared to 7.6%) than that of the first sample and its ash analysis was very different. The ratio $\frac{\text{SiO}_2 + \text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$ for 616/44 was 34.8 and % CaO was 2.0. The wide difference between these two samples of coal from the same mine illustrates a probable difficulty in the chemical treatment of stoker coals.

The iron compound added in the chemical treatment of this coal was Ferrite Yellow, an ochre obtained from the Edmonton Paint and Glass Company. Its analysis follows:

Fe ₂ O ₃ %	85.2
Al ₂ O ₃	10.0
CaO	1.2
Moisture	1.0
Unaccounted	2.6

1.96 pounds of Ferrite Yellow were required per 100 pounds of 616/44. This increased the ash from 10.5 to 12.4, lowered the calorific value from 13,790 B.t.u./lb. to 13,500, and decreased the softening temperature from +2685° F. to 2370° F. Figure XIII shows the cone series of the original coal (seventh cone series) and the chemically treated coal (sixth cone series).

A forty-eight hour run using the 15' on 15' off periodicity was made and clinkers were removed every twelve hours. Clinkering was very satisfactory and the combustion bed showed no signs of building up. As noted before the increase in ash has little or no effect in interfering with the normal operation of the stoker because a larger weight of clinkered ash occupies a smaller volume than a lesser weight of unfused ash. Table XI is a partial summary of the work on chemical treatment of 616/44.

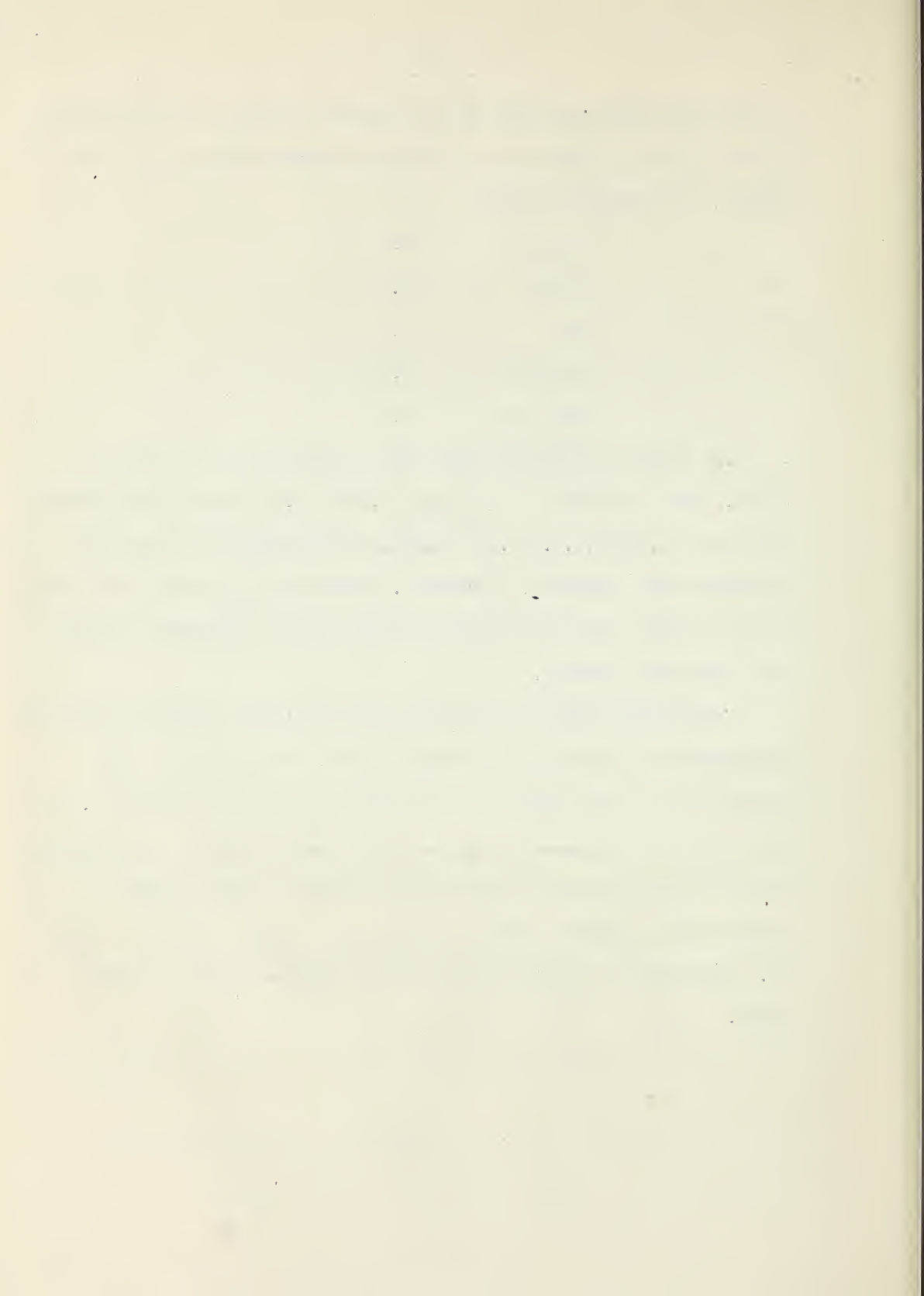


TABLE XI

Chemical Treatment of 616/44

	Original Coal	Chemically Treated Coal	Ash Analysis for original coal		
Calorific Value B.t.u./lb.	13,790	13,500	SiO ₂	%	58.5
Ash %	10.5	12.4	Al ₂ O ₃	%	33.4
Ash (pounds per therm)	0.76	0.92	SO ₃	%	2.2
Softening Temperature	+2685° F.	2370° F.	Fe ₂ O ₃	%	2.6
<u>SiO₂ + Al₂O₃</u> Fe ₂ O ₃	35.3	5.1	CaO	%	2.0
Clinkering	nil	Very satis- factory			

The feasibility of adding chemicals directly to the coal in the fire-bed was suggested in view of its greater economic possibilities. If this type of chemical treatment were possible, the cost of adding chemicals in the preparation of the coal could be avoided. The iron compound could be supplied to the consumer who would be instructed to add it according to the needs of the combustion bed. Naturally the proper ratio of SiO₂ + Al₂O₃ would very seldom be attained, but likely the Fe₂O₃ consumer, after some practice, would develop his own scheme for adding the iron compound to obtain satisfactory clinkering.

A forty-eight hour run was made in the underfeed stoker, Ferrite 616 in Yellow being added directly to the firebed. During the run coal and unfused ash were deliberately allowed to pile up in the retort area to simulate what would likely happen in a household stoker. Then a weighed quantity of Ferrite Yellow, calculated for the amount of coal that had been burned, was sprinkled over the firebed and mixed into the refuse. No satisfactory

clinkers were formed and the coal continued to pile up in the furnace until unburned coal and loose ash had to be removed with a shovel. The above illustrates what would very easily happen in a household stoker; no householder would tolerate the dust and smoke caused by having to remove unburned coal and loose refuse with a shovel.

It may be concluded that if such an Alberta coal as this Cascade sample is to be treated with chemicals, then this treatment must be done in the preparation of the coal.

Sample 617/44, a coking medium volatile bituminous coal, was also treated with an iron compound in an attempt to make it clinker satisfactorily. The trial was not satisfactory and no further work was done along this line because of the strong 'coke-trees' formed by this coal in the underfeed.

The iron compounds used were expensive, but were used only as an experiment. After consultation with Dr. J.A. Allan regarding naturally occurring ochre deposits, it was decided to experiment with these ochres in treating coals. However the approach of winter forced this side investigation to be postponed, since the known ochre beds rich in iron are in the mountains and are inaccessible in winter.

C. Effect of Blending.

Blending of refractory ash coals with coals having a fusible ash is a common commercial procedure to obtain a fuel which will clinker in an underfeed stoker. Blending is also used to prevent the formation of strong 'coke-trees' by coking coals. The coking coals in Alberta generally have infusible ashes so that blending with fusible ash coals may improve the coking coals in two ways: by partially preventing the formation of 'coke-trees' and by producing a clinkering ash.

A number of stoker tests were made on blended coals; a summary of these tests follows.

Blending with Non-coking coals.

616/44, a semi-anthracite (non-coking) coal from Cascade area, was blended with a lower rank coal, 618/44, from Camrose Area. Table XII summarizes data relevant to this blending experiment.

TABLE XII

Blending of 616/44 with 618/44

	616/44	618/44	75% 616/44 25% 618/44
Calorific value B.t.u./lb.	13,790	8,470	12,460
Ash %	10.5	7.3	9.8
Ash (pounds per therm)	0.76	0.90	0.79
Softening Temp. of Ash	+2685° F.	2145° F.	2685° F.
Clinkering	nil	Not tested in underfeed	Very satis- factory

Stoker tests were made using the 15' on 15' off, 10' on 30' off, 2' on 58' off periodicities on a blend of 75% of 616/44 and 25% of 618/44. The two fastest rates of operation gave very satisfactory clinkering but the refuse from the stay-alight rate was not clinkered. This latter point was not considered important since a household stoker usually operates for longer than two minutes each hour at least several times a day during even the mildest weather.

One run was made at the 15' on 15' off periodicity using a blend of 50% of each coal, but no perceptible difference was noted in the clinkers formed.

In blending lower rank coals with high rank coals, the minimum amount of the former which will produce a satisfactory clinker should be used to keep the calorific value of the fuel as high as possible. An insufficient amount of 618/44 remained after these runs to permit tests being made on blends with lower than 25% lower rank coal. On a commercial basis, however, it would be unwise to use less than 25% of the lower rank coal since the ash fusion temperature for coals from the same mine often varies considerably, and a blend with less than 25% of the lower rank coal might occasionally give trouble from poor clinkering.

The cone series of the ash of the blend of 75% 616/44 and 25% 618/44 is illustrated in the eighth cone series in Figure XIII. The seventh (616/44) and ninth (618/44) series illustrate the ash fusion temperatures for the coals used in the blend. Blending has lowered the softening temperature from +2685° F. to 2685° F., and has decreased the calorific value by 1330 B.t.u./lb. Although the ash percentage has been decreased from 10.5 to 9.8, the ash calculated on the basis of pound ash per therm. of heat release has been increased from 0.76 to 0.79.

25% of another lower rank coal, 619/44 from Taber area was blended with 75% of 616/44. Clinkering was poor. The softening temperature of the ash of 619/44 was 2380° F.; this was 235° F. higher than that for 618/44.

The above trials on blending illustrate that the lower rank coal used to reduce the refractory nature of the high rank coal ash should have a low softening temperature so that a small amount of the lower rank coal can be used and so keep the calorific value of the blended fuel as high as possible.

Blending with Coking Coals.

617/44, a medium volatile bituminous coal (strongly coking) from Mountain Park area produced unsatisfactory clinkers in the underfeed stoker. Very small pieces of fragile clinker were formed which were too small to allow removal. Strong 'coke-trees', sometimes two feet in height, formed in the retort area and when these 'coke-trees' broke, much of the combustible matter fell out of the hot fire zone. The refuse thus consisted of a small amount of loose ash and a large amount of unburned coke. These unburned pieces of coke were raked back into the hot fire bed, but owing to the poor clinkering nature of the ash, no way of removing the refuse was possible except by means of a shovel.

It was noted that 'coke-tree' formation gave less difficulty when the combustion bed was allowed to build up to a depth of approximately sixteen inches. With a deep fire-bed a coke formation at the tuyere level of the retort was pushed up through the hot fire giving the coke a better chance to burn. 'Coke-trees' still protruded above the fire-bed, but they were of weaker structure. They usually collapsed before building up higher than a foot and thus tended to fall into the hot fire zone rather than outside of it.

617/44 was blended with 618/44 in ratios of 3:1, 2:1 and 1:1. Coking appeared to give as much trouble with the 3:1 and 2:1 blends as with the original coal but the 1:1 ratio gave notably less coking trouble. However, satisfactory clinkering was not obtained with any one of the three blends. One run was also made using 40% of 619/44 and 60% of 617/44, but again no satisfactory clinkering was obtained.

It should be noted that the softening temperature of 617/44 was 2595° F. while that for 616/44 was +2685° F., yet the latter coal gave a very

satisfactory clinker with 25% of 618/44 while the former when blended with the same lower rank coal did not clinker satisfactorily. The explanation for this peculiarity probably lies in the coking nature of 617/44. When the blended fuel reaches the burning zone, the pieces of free-burning lower rank coal are ignited easily and burn quickly. The coking coal loses its volatile matter, becoming plastic in doing so, and forms a coke which burns slowly as it is pushed up through the fire bed. Thus there is segregation of the refuse from the two coals, the low rank coal ash forming small clinkers around the edge of the retort and the coking coal ash, which makes up the largest bulk of the refuse, being found on the top and sides of the fire bed. This segregation of the refuse was noted in the fire bed particularly with the 1:1 blend.

The coking tendency of 621/44, a medium volatile bituminous coal from Crowsnest area, was less pronounced than it was for 617/44, but its ash was more refractory in nature, its softening temperature being +2635°F. When blended with 619/44, and when the fire bed was allowed to become deep, it showed no tendency to coke badly. However blending of 621 with 618 did not produce a satisfactory clinker.

It may be concluded that a strongly coking coal is not suited to such an underfeed stoker as the one used in this investigation. A recent publication by Charles E. Sawyer and Walter Knox (19), on work done for Koppers' Company, makes a number of suggestions regarding the use of coking coals in underfeed stokers. Most of these suggestions are not applicable to the work being done by the Research Council since they have to do with modification of stoker design. Suggestions which are useful are:

(a) insufficient air supply aggravates the formation of large blocky coke,

although raising the air above 30 to 40 per cent excess air does not further improve the character of the coke formed, (b) increasing the coal feed results in a somewhat more friable coke structure, and (c) increasing over-fire draft improves the character of the coke formed and reduces troublesome accumulations by accelerating off-period burning.

Suggestions (a) and (c) above were tried in the stoker tests on 617/44 and 621/44 and were found to reduce 'coke-tree' formation very little.

D. Effect of Washing.

While a suitable underfeed stoker fuel must have enough ash to protect the tuyeres from the intense heat of the combustion bed, still the ash content must not be excessively large so that the refuse accumulated between clinker removals interferes too much with the normal operation of the stoker. In this investigation the difficulty experienced in regard to the ash content of the coals tested in the underfeed was not that the ash content was too small, but, rather that, it was too large. The possibility existed that many of these high ash coals could be made more satisfactory for underfeed stokers by reducing the ash content. This reduction would be made by better preparation which might include wet or dry washing.

The fusion temperature of the original coal ash may or may not be different from the fusion temperature of the washed coal ash, i.e., washing may change the clinkering nature of the coal ash depending upon the distribution of the inorganic constituents in the coal.

No stoker tests were made to compare the clinkering properties of washed and unwashed coals owing to the difficulty of washing a large sample on a laboratory basis or a small sample in a commercial washery. However three coals were investigated on a laboratory scale, using a

solution of benzene and carbon-tetrachloride of 1.445 specific gravity. Chemical analyses of the ash and ash fusion tests were done on the three floats. The following table summarizes the results.

TABLE XIII
Effect of Coal Washing on the Ash of Three Coals

Sample	% Ash	Ash Softening Temperature	% SiO ₂	% Al ₂ O ₃	% SO ₃	% Fe ₂ O ₃	% CaO
602/44 (original)	17.0	2360° F.	60.5	23.3	2.3	3.6	9.5
602/44 (float)	7.3	2325° F.	60.3	24.7	3.9	3.7	6.6
605/44 (original)	8.8	2235° F.	42.8	23.6	6.1	8.7	15.5
605/44 (float)	4.7	2245° F.	39.5	28.3	6.2	10.7	10.5
607/44 (original)	13.5	2290° F.	52.9	27.1	4.5	5.1	7.5
607/44 (float)	7.7	2265° F.	48.5	28.4	3.4	5.7	8.7

Figure XIV illustrates the cone series for the ashes of the three coals and three floats.

Sample 605/44 (original), a coal with a low enough ash for satisfactory use in an underfeed stoker, produced clinkers that were too dense, i.e., the refuse formed blocky chunks of non-porous clinker. As an experiment a washing test was done on this coal even though a coal with 8.8% ash is not usually considered for washing on a commercial basis. It is to be noted from the above table that the ash has been decreased approximately fifty per cent by washing, and the ash fusion temperature is approximately the same as for the unwashed coal. Considerable decreases are noted in % SiO₂ and CaO, while increases occurred in % Al₂O₃ and Fe₂O₃. No definite prediction can be made regarding the probable type of clinkering, but it is likely that there would be little difference between the clinkers formed from the original and washed coals.

The % ash in 602/44 was definitely too high for satisfactory stoker use. This washing test decreased the ash by more than fifty per cent and lowered the softening temperature of the ash slightly. It is probable that this coal would produce a very satisfactory underfeed stoker fuel, since the main criticisms of the original coal were the high percentage of ash and insufficient clinkering; a small reduction in the ash fusion temperature would probably tend toward better clinker formation.

The clinker formation of the ash of 607/44 original was satisfactory but, as noted previously, the ash content was too high for satisfactory use in an underfeed stoker. Washing would probably produce a satisfactory stoker fuel from such a coal as 607/44.

Sample No.

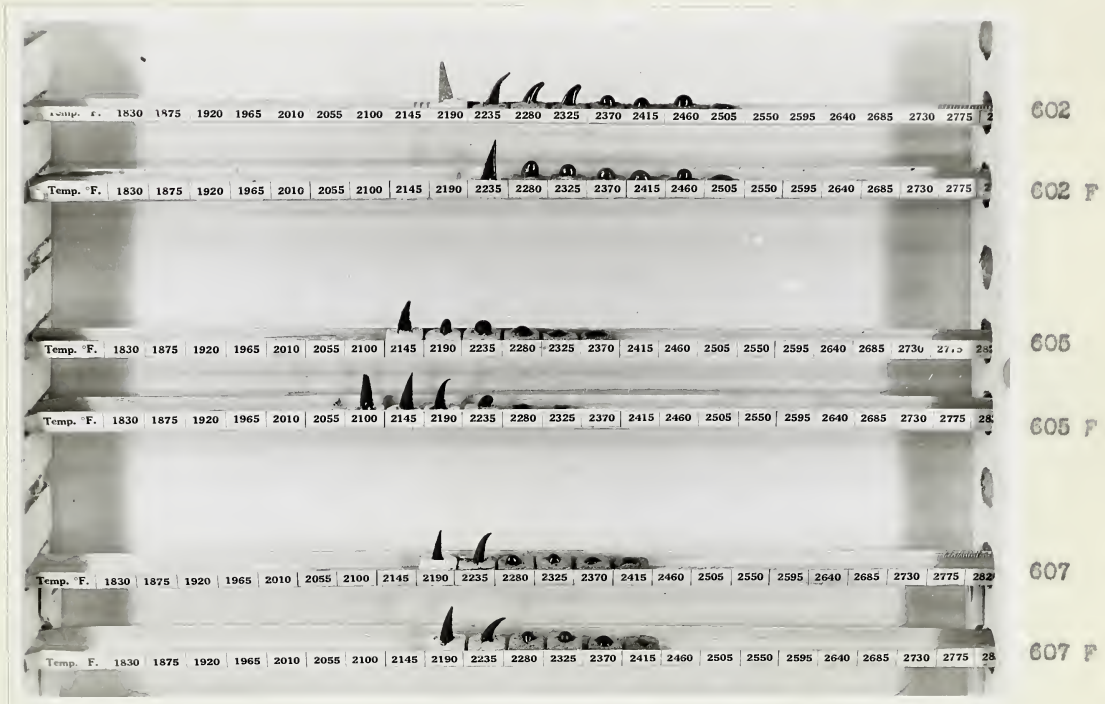


FIGURE XIV - Cone Series to Show the Effect of Coal Washing on the Fusion Temperatures of the Ashes of Three Coals.

SMOKE TESTS

A. Introduction.

The tendency of a coal to produce smoke while it is burning is one of the properties which determine the proper use of the coal. Smoke does represent a small loss of heat value, but worse features are that it pollutes the atmosphere and causes the deposition of an insulating layer of soot on radiation surfaces in the furnace and flue pipes and thus causes a serious decrease in efficiency of heat transfer. This soot must be removed once or more per heating season to keep the efficiency of a heating unit up to a reasonable level and to prevent chimney fires. Many cities have by-laws which forbid pollution of the atmosphere by smoke.

A coal may produce excessive smoke in one installation while it may prove quite satisfactory in another. To illustrate, consider the combustion of a moderately smoky coal such as 605/44 from Saunders area. In the underfeed stoker the coal is subjected to a gradual preheat before it reaches the fire-bed. The volatile matter distilled off in this preheat must pass up through the fire-bed before it reaches the chimney. For 605/44 the volatile matter was almost completely burned before leaving the combustion chamber and thus no smoke was noted issuing from the chimney.

In the overfeed stoker 605/44 exhibited moderate smokiness at all times during the 15' on 15' off and 10' on 30' off runs. In this stoker the coal is pushed on at the end of the retort about eight inches away from the active combustion zone. Thus the fresh coal suddenly is subjected to an intense heat causing the volatile matter to be distilled off quickly. The volatile matter does not pass up through the burning zone but is carried directly into the radiator and flue pipe and thence into the chimney.

That is, it quickly reaches a relatively cool part where combustion can no longer take place and thus some of the volatile matter issues from the chimney as smoke.

The smokiness of 605/44 in the overfeed was worse than usual for approximately one minute at the beginning of each off period. During this time fresh coal was still being subjected to an intensely hot fire and the volatile matter was still being distilled off. But the latter was not supplied with sufficient air for the normal amount of combustion in the furnace and flue pipes; thus excessive smokiness lasted until combustion slowed down.

Bituminous (coking) coals are apt to produce excessive smoke in under-feed stokers. These coals have a high volatile content and form 'coke-trees' in the combustion chamber of the furnace. Just before the coal reaches the burning zone it forms a soft plastic mass and much of the volatile matter is released quickly. The plastic mass then becomes hard forming 'coke-trees'. The latter cause channelling of the air supply and thus the volatile matter rising through the fire-bed is not well mixed with air and some of it escapes from the combustion chamber without being burned and issues from the chimney as smoke.

The bituminous (coking) coals are smoky because the usual methods of firing do not distribute the air supply well enough to burn the high volatile content efficiently. Bituminous coals which are non-coking, e.g., high volatile C bituminous, are not difficult to burn and do not produce excessive smoke, even though the volatile matter content is approximately the same as for the coking coals. Lower rank coals, whilst possibly having as high a volatile content as the coking bituminous coals, have a high oxygen content and a low ignition temperature and thus tend to burn freely without smoke.

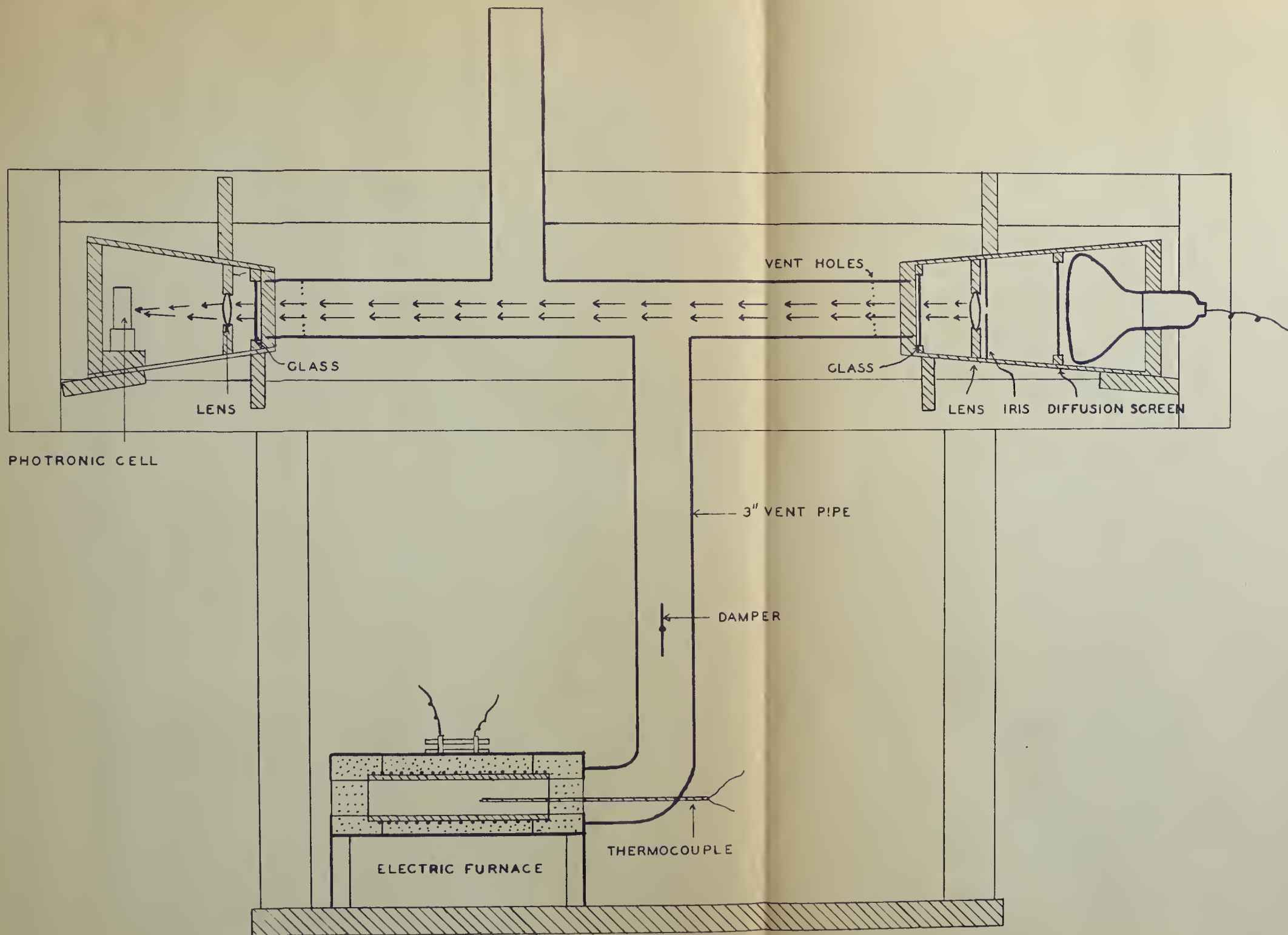
B. Construction of Apparatus.

The apparatus as illustrated in Figure XV was constructed to give a quantitative measure of the amount of smoke produced by a coal during its combustion, after two early attempts to measure smoke by visual observation proved fruitless. The third apparatus was designed so that the smoke produced by a coal interferes with a beam of light falling upon a photronic cell. The amount of this interference is measured by a micro-ammeter which registers the photronic cell current.

A sheet iron box, 14" long, 5 1/4" wide, and 4 1/2" deep, standing on four 4" legs, encloses an alundum tube 10" long and 2" in diameter (inside). The outside of the alundum tube is spirally grooved and is wound with eighty-seven full turns of 16 gauge nichrome wire; alundum plaster about 1/4" thick covers the wire on the outside of the tube. Insulating brick fitted around the tube holds the latter in place so that the openings at each end of the tube are directly connected to 2" openings in the ends of the box.

One end of the furnace is fitted with a 3" collar for attaching the chimney of 3" vent pipe. A chromel-alumel thermocouple is held in position so that its bare wire end is approximately at the center of the furnace. A damper was put in the first length of vertical pipe above the furnace as shown in Figure XV. The total length of vertical pipe measured from the bottom of the 2" furnace opening is 49". The horizontal distance between the centers of the vertical sections of the double T pipe, i.e., the horizontal distance where the smoke interferes with the beam of light, is 7 3/4" in length.

SMOKE FURNACE



SCALE 0 6 12 18 INCHES

As shown in the figure wooden boxes enclose the light source, lenses, photronic cell, etc. One side on each box is hinged at its end so that the side opens out from the box. The light source is a 150 watt reflector type Mazda lamp; the inside of the box enclosing this lamp is lined with asbestos. A lens, 5 cm. in diameter, is so placed that its focal point is approximately centered on the lamp filament in order to obtain a nearly parallel beam of light through the horizontal pipe. At first a diffusion screen was placed at the focal point between the lens and the light source, but the screen did not permit enough light to reach the photronic cell to give a reasonably large microammeter reading. An iris placed between the light source and the lens stops light going through the outside part of the lens and thus prevents some aberration. The opening in this iris is $1 \frac{11}{16}$ " in diameter.

A small pane of 'X-ray plate' glass protects each lens from smoke and heat damage; the glass tightly covers the opening of the box into which the horizontal pipe fits. The photronic cell is so placed that the beam of light focussed through the lens strikes the center of the cell's face. It was found that consistent results could only be obtained by placing an iris between the lens and the photronic cell to allow the primary beam of light to strike the cell but to prevent the secondary ring from striking the cell. The diameter of the opening in this iris is $5/16$ ".

In the first model of this apparatus the two wooden boxes were placed close to the ends of the horizontal part of the double T pipe. During each run with this first ^{model} apparatus soot was deposited on the glass plates and a correct measure of the smokiness of a coal could not be obtained. To prevent this deposition of soot, the upper framework was extended to

permit the insertion of a 12" length of horizontal pipe between the ends of the double T pipe and the wooden boxes. Sixteen vent holes each 1/16" in diameter were bored in these 12" lengths of pipe approximately 1/2" away from the ends of the boxes to permit a slight positive draft away from the glass windows. No trouble is now encountered with soot deposition.

C. Test Procedure.

To correlate smoke results for a coal obtained from this furnace with the smokiness of this coal in actual practice, a proper balance between the furnace temperature and the natural draft of the chimney had to be secured. After some experimentation it was decided to place the coal in the open end of the furnace in such a way that the coal would catch fire and all the smoke would be driven off in approximately one minute. It was found that this required a furnace temperature of $850 \pm 10^{\circ} \text{C}$. when the coal was placed in the furnace $2 \frac{3}{4}$ " from the open end. The draft obtained from 49" of vertical pipe (with damper open) gave smoke results for several typical coals consistent with the known smoking properties of these coals.

Then a suitable amount and a suitable sizing of sample were selected. After considerable experimentation the amount of sample chosen was 1.0 ± 0.1 gram and the sizing chosen was through 4 mesh (0.185") and retained on 8 mesh (0.093") standard Tyler screens.

In making a smoke test the furnace is plugged at its open end and is heated to 850°C . A one gram sample of 4-8 mesh coal is weighed out. The light is switched on and the microammeter reading adjusted to eighty microamperes by means of a variable rheostat. The plug is then removed and the sample of coal placed in the furnace $2 \frac{3}{4}$ " from the open end by means

of a spoon with a bar across its handle. Microammeter readings are then taken at intervals of five seconds until the readings again reach eighty microamperes. Three runs are usually made and the results averaged. The average readings for the five second intervals are subtracted from the initial reading and the numbers obtained are expressed as percentages of the initial reading. These percentages of light absorbed are then plotted against time in seconds. The curve obtained illustrates the smokiness of the coal. Curves for four typical coals are shown in Figure XVI.

Five suggestions were followed in attempting to give a numerical value to the smokiness of a coal. These five methods were:

- (1) the maximum per cent light absorbed.
- (2) the area under the curve expressed as a percentage of the total area.
- (3) the average per cent of light absorbed over the thirty seconds interval of most smoke.
- (4) the average per cent of light absorbed over the twenty seconds interval of most smoke.
- (5) the average per cent of light absorbed over the ten seconds interval of most smoke.

Three typical coals were used and it was found that (4) gave the most consistent results. The degree of smoke for a coal is defined as the average per cent light absorbed during the twenty seconds interval of most smoke.

D. Results to Date.

It has been realized for some time that the smokiness of a coal is related directly to the rank of the coal. The higher and lower rank coals

are smokless while the medium rank coals (bituminous) are smoky. This is shown very clearly in Table XIV and in Figure XVII. Also these show a close relationship between the degree of smoke and oxygen content. It should be noted that this oxygen content is on the dry basis, i.e., it does not include the oxygen of the moisture present in the coal substance. There is a rapid progression in degree of smoke to a maximum as the oxygen content increases (and as the coal rank decreases) from zero to approximately eight per cent. Ninety-five per cent degree of smoke is associated with high volatile A and B bituminous coals and with eight per cent oxygen. There is then a rapid retrogression in degree of smoke as the oxygen content increases (and as coal rank decreases) to approximately 16.5%.

Figure XVII cannot be used to calculate the approximate degree of smoke in a blended fuel such as 616/44 (semi-anthracite) plus 612/44 (subbituminous C). In this case the oxygen content (calculated - 5.8%) would suggest that the blend should have a degree of smoke of approximately ninety per cent, yet this blended fuel is definitely smokless.

TABLE XIV

Degree of Smoke, Rank and Oxygen Content of 32 Coals

Sample	Area	Rank	Degree of Smokiness %	Oxygen Dry Basis
610/44	K 7	Semi-Anthracite	3.6	2.8
616/44	K 7	" "	8.7	2.2
2/45	K 8	Low Volatile Bituminous	11.9	4.4*
1/45	K 8	" " "	27.1	4.4*
10/41	K 4	" " "	53.1	0.7
26/43	K 10	Medium " "	74.1	6.0
15/43	K 10	" " "	74.6	5.1
5/42	K 3	" " "	76.3	3.9
621/44	K 10	" " "	76.6	4.8
3/42	K 3	" " "	82.5	5.5
25/43	K 10	" " "	82.7	4.9
617/44	K 3	" " "	91.6	4.6
11/44	K 10	High Volatile A "	92.3	5.4*
606/44	Ken- tucky	" " " "	96.6	6.5
16/43	B 7	" " B "	93.2	6.1
5/43	B 6	" " " "	94.0	9.7
601/44	B 9	" " C "	78.4	11.1
605/44	B 4	" " " "	69.6	12.0
607/44	B 9	" " " "	69.0	12.1
612/44	B 3	" " " "	57.8	13.1
615/44	B 14	Subbituminous B	45.9	13.0
604/44	E 10	" "	40.9	12.9

TABLE XIV (cont'd)

Degree of Smoke, Rank and Oxygen Content of 32 Coals (cont'd)

Sample	Area	Rank	Degree of Smokiness	Oxygen Dry Basis
620/44	E 8	Subbituminous B	30.2	13.1
619/44	B 12	" "	29.0	12.8
609/44	E 10	" "	18.8	15.4
603/44	E 2	" "	18.3	15.3
614/44	E 1	" "	6.9	16.3
622/44	E 2	" C	23.2	16.3*
608/44	E 3	" "	18.7	15.8
613/44	B 13	" "	9.2	14.8
611/44	E 9	" "	8.2	17.3
618/44	E 4	" "	7.0	16.3

* assumed values

FIGURE XVI

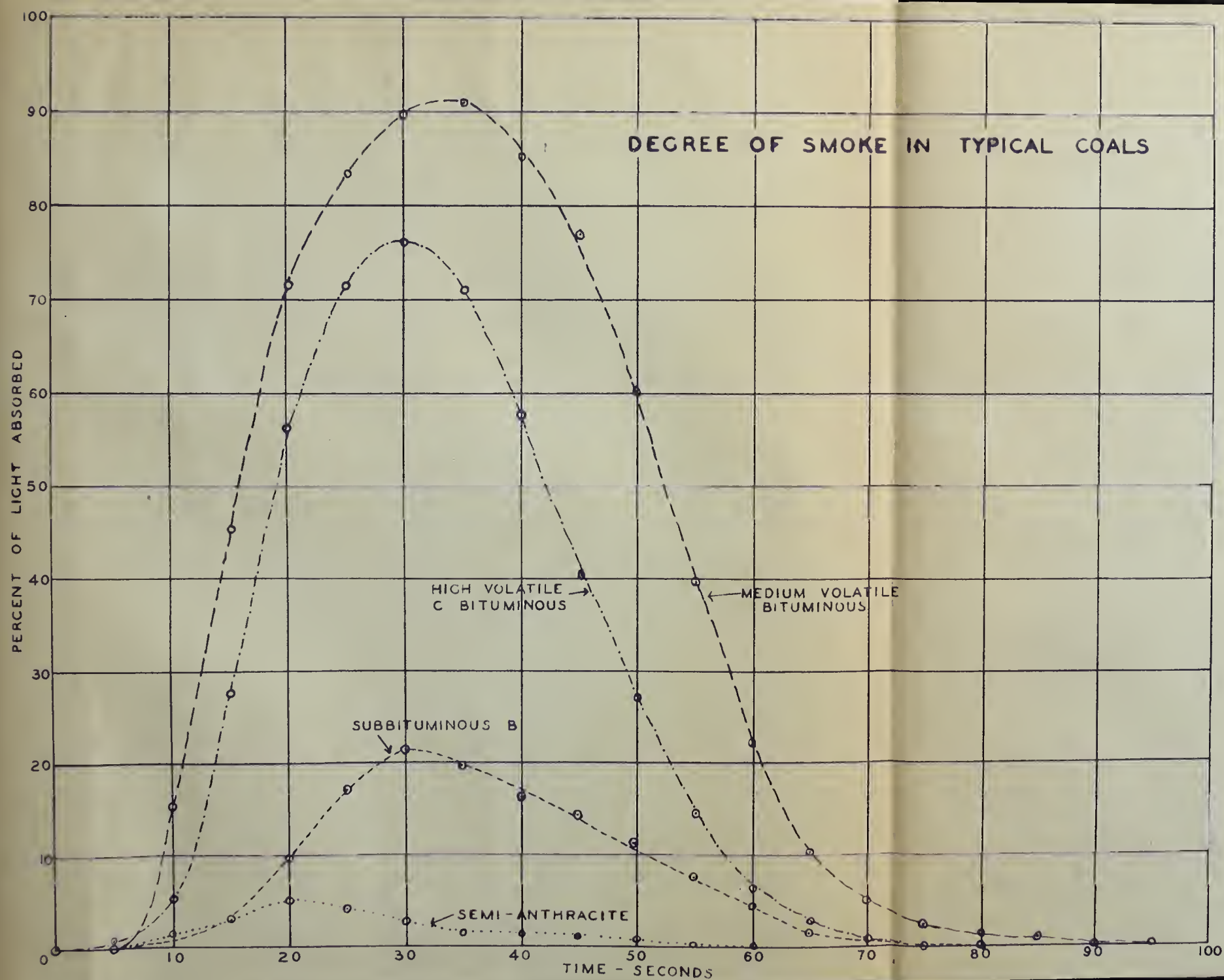
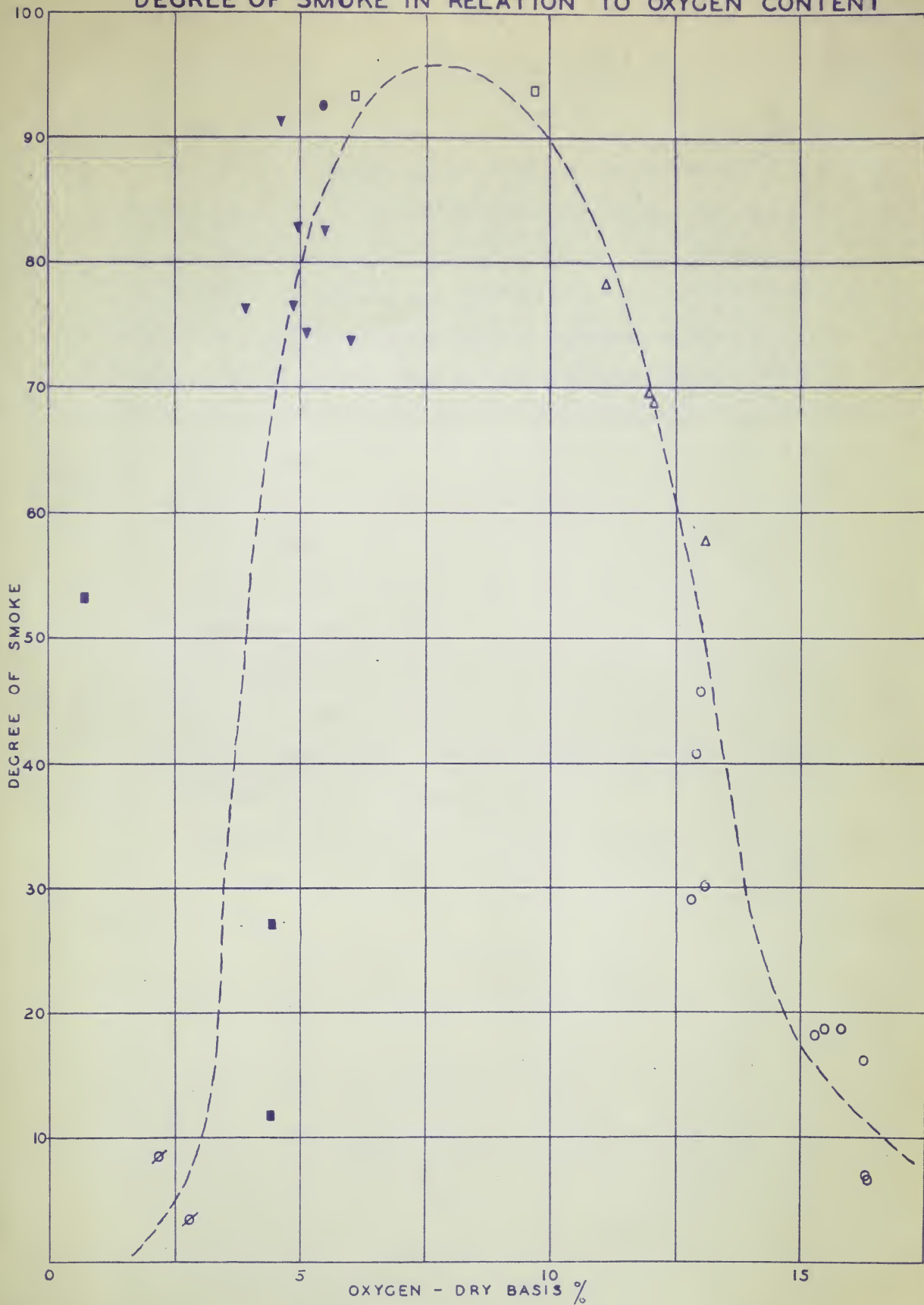


FIGURE XVII

Legend

- Ø - semi-anthracite
- - low volatile bituminous
- ▼ - medium volatile bituminous
- - high volatile A bituminous
- - high volatile B bituminous
- Δ - high volatile C bituminous
- - subbituminous B and C

DEGREE OF SMOKE IN RELATION TO OXYGEN CONTENT



E. Suggested Modifications

Owing to war time restrictions on the sale of microammeters and photronic cells, the instruments ordered months earlier for this smoke testing apparatus arrived just as this thesis was being written. The smoke results presented here were obtained with instruments borrowed from the Departments of Chemistry and Physics, University of Alberta.

These results indicate that the method is good, although not yet satisfactory, and that modifications of the apparatus are worthwhile and advisable before publication of the method.

The proposed modifications include: re-wiring of the furnace and setting it in a vertical position instead of horizontal. When the furnace is re-wired, it will be possible to maintain its temperature at the desired level with the full natural draft of air through the furnace. With the vertical furnace, it is proposed to raise the coal up into the furnace in a gauze crucible to the desired height without having the coal touch the hot furnace walls. The gauze crucible will also obviate the difficulty of the proper placement of coal.

A suggested modification in the procedure is the use of a variable weight of sample, i.e., to test a constant heat value rather than a constant weight.

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